PUBLIC ROADS

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UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

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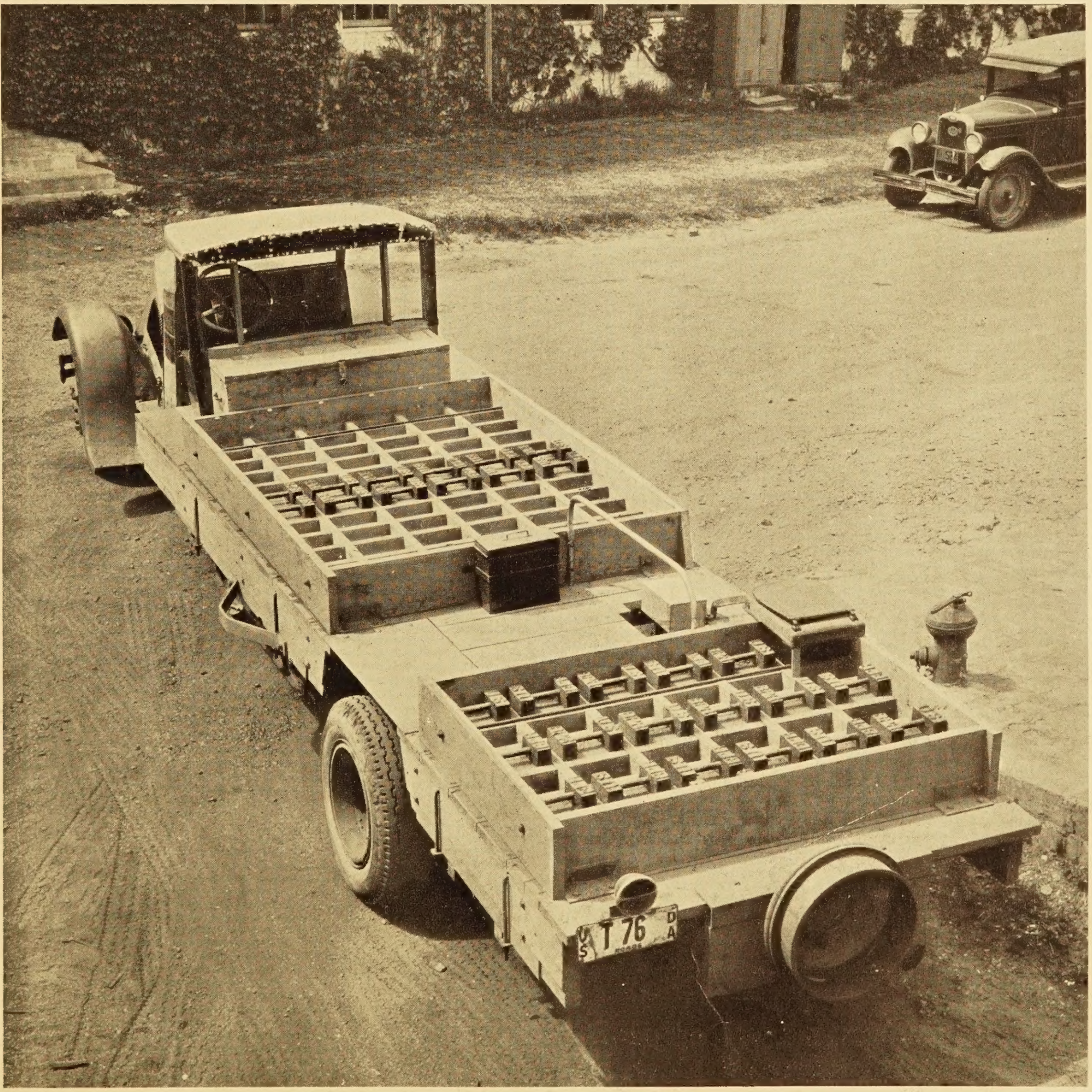

BUS CHASSIS USED IN IMPACT TESTS

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IMPACT REACTIONS DEVELOPED BY A MODERN MOTOR BUS

Reported by **JAMES A. BUCHANAN**, Associate Engineer of Tests, U. S. Bureau of Public Roads

ONE of the most important trends in the use of highways to-day is that toward higher vehicle speeds, particularly with the heavier wheel loads. At the present time, this trend is most evident in motor bus operations, although fast-freight highway transportation is a rapidly developing industry. This condition of heavy wheel loads operating at sustained high speeds has been made practicable by the comparatively recent introduction of high-pressure and balloon tires adequate for and economical in such service. A study of the impact reactions produced on pavements by vehicle wheels under such intensive operating conditions was the object of a research investigation recently completed by the Bureau of Public Roads with the cooperation of the Rubber Manufacturers' Association and the Society of Automotive Engineers.

In arranging a schedule of tests to be followed several factors relating to equipment and scope of conditions were considered. The vehicle and tire equipment should be representative of modern high-speed traffic. The loads and speeds should cover an adequate range in operating conditions. The roughness conditions should involve both artificial and natural obstructions, the artificial obstructions bringing out the influences of various factors on impact reactions and the natural obstructions indicating the actual forces developed under operating conditions.

Figure 1 gives a general view of the vehicle used. It is a modern high-speed bus chassis on which a special body was built to meet the needs of the tests. The floor of this body was divided into a number of small compartments, as shown on the cover page, for retaining 100-pound cast-iron weights used to vary the load conditions. The wheel base is 233 inches. Each rear spring is provided with overload booster leaves which operate in two stages. In order to provide clearance between the rear spring and the large dual tires tested, it was necessary to apply a spacer ring on each rear hub between the flange and the inner wheel disc. These 1½-inch wide spacers remained in place throughout the tests so that all tires would be tested under the same conditions. This proved to be an unnecessary precaution, as accelerations obtained with 7 and 9.00 inch dual tires before the spacers were applied were the same as those obtained afterwards.

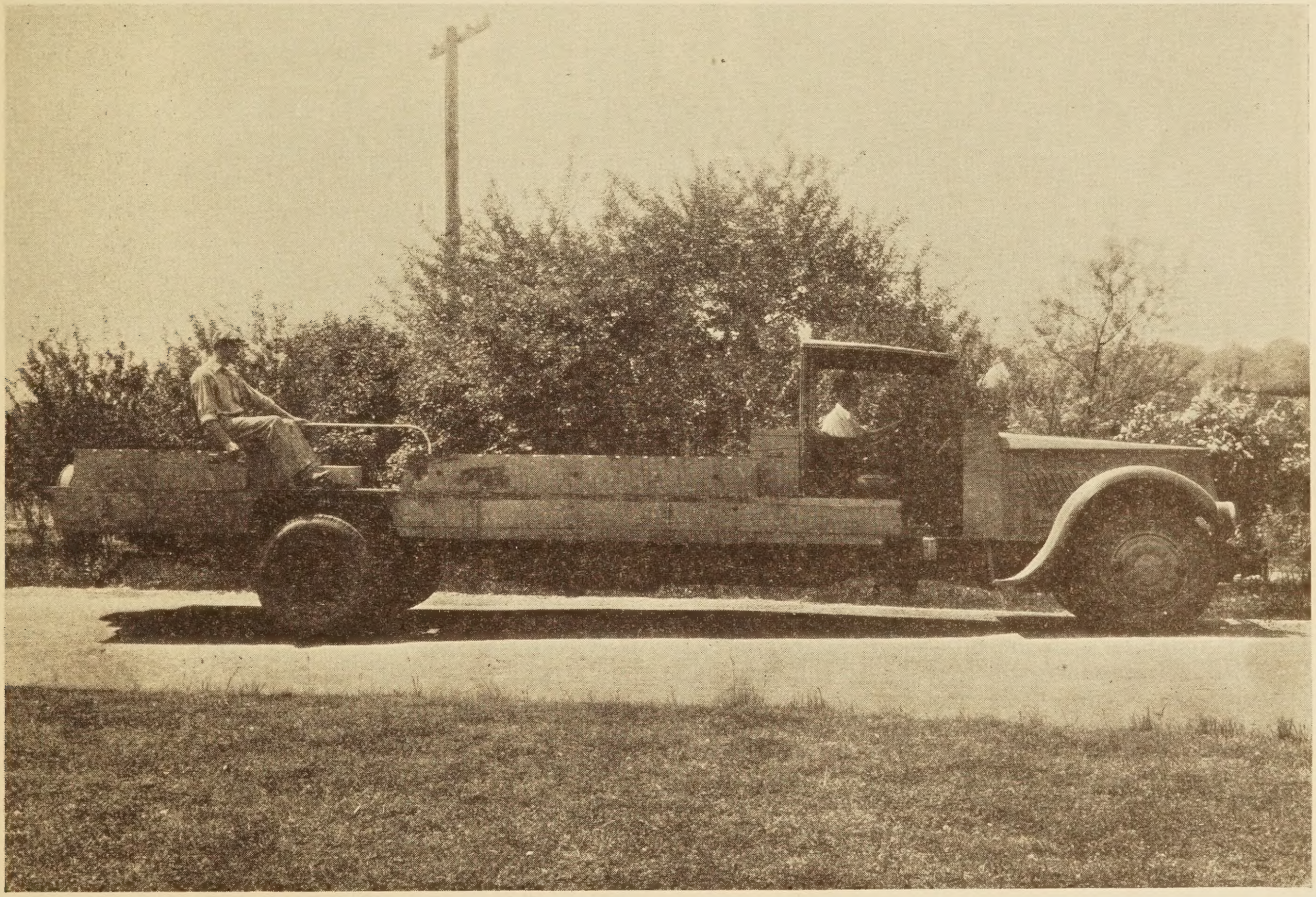

FIGURE 1.—GENERAL VIEW OF BUS USED IN IMPACT TESTS

TIRE EQUIPMENT SELECTED TO COVER TYPES IN ACTUAL USE

The tire equipment tested included both the high-pressure pneumatic and the low-pressure pneumatic or balloon types. The range in section size was from 7-inch high-pressure to 12.00-inch low-pressure and inflations varied from 107 to 53 pounds per square inch. Two rims diameters were used—20 and 24 inch.

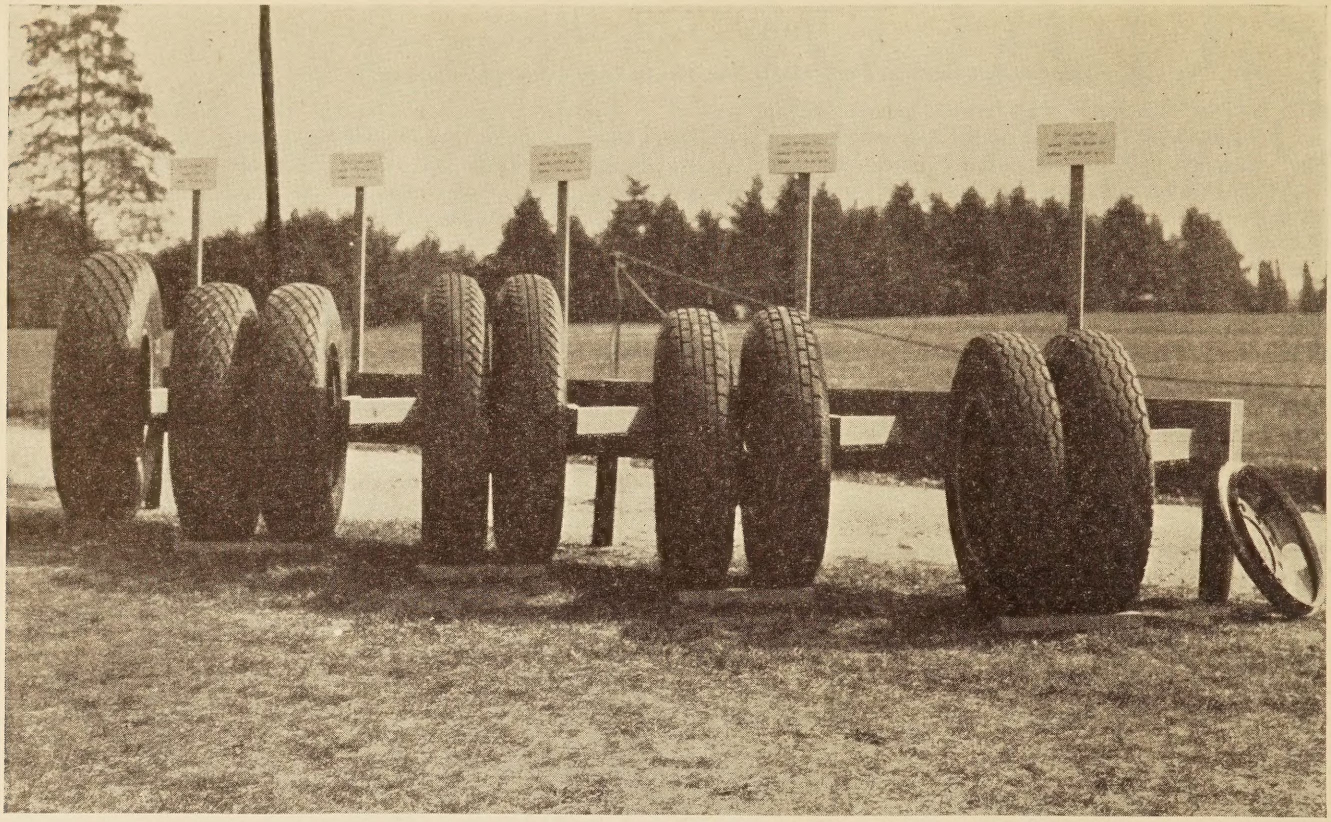

Figure 2.—Some of the Tire Equipment Used in the Bus Tests

The tires were mounted directly on appropriate disc wheels prior to the tests, and tire changes were quickly effected by changing these disc wheels, which were bolted on the hub centers of the bus chassis.

A general view of the range in tire sizes is given in Figure 2. The tires were the products of four manufactures, but all had conventional tread designs used in modern commercial and bus service.

A complete list of the tire sizes tested is given in Table 1, together with the inflation pressure and load conditions selected for each tire. In determining these pressures and loads, three factors were considered. First, it was desirable to make comparisons on an equal load basis. Second, it was desirable to include tests conforming as closely as possible with recommended standard practice. Third, it was desirable to include test conditions varying from recommended practice for at least a part of the range found in actual operating conditions. The recommended or standard inflation pressures for various loads on balloon and high-pressure tires were obtained from the Yearbook of the Tire and Rim Association, published April, 1930, and are given in Tables 2 and 3. In this connection it is interesting to note that the actual practice of eight fleet operators using more than 5,000 buses was ascertained through a survey recently conducted by the National Association of Motor Bus Operators and was found to range from recommended inflation pressures and loads to rather severe overload and under-inflation conditions.

The various tire and rim sizes, loads and inflation pressures, as shown in Table 1, provided for the determination of the influence of such factors as inflation pressure, load, tire type, tire section, rim diameter, rim width, and single versus dual mounting. The wheel loads and other data for the various combinations are given in Table 4.

Table 1.—*Tire, rim, load, and inflation conditions*

Tire section	Rim diameter	Rim width	Tire plies	Dual spacing	Inflation pressure used with—					
					3,000-pound load per tire	3,500-pound load per tire	4,000-pound load per tire	4,700-pound load per tire	6,000-pound load per tire	8,000-pound load per tire
Inches	*Inches*	*Inches*		*Inches*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
7	20	7	10	10½	107, 100, 93, 86	100	100	100	--------	--------
7	24	7	10	10½	93	--------	--------	--------	--------	--------
9.00	20	7	10	10½	65, 61, 57, 53	65	65	65,75	--------	--------
9.00	24	7	10	10½	54	63	--------	--------	--------	--------
9.00	20	8	10	12	61	--------	--------	--------	--------	--------
9.75	20	8	12	12	55	--------	71	80	--------	--------
10.50	20	9–10	12	12¾	--------	--------	63	75	--------	--------
[1] 12.00	20	11	14	(Single)	--------	--------	--------	--------	82	95

[1] The single 12.00 by 20 inch balloon tire at an inflation pressure of 82 pounds per square inch has the same rated carrying capacity as the dual 9.00 by 20 inch balloon tires at 61 pounds per square inch and the 34 by 7 inch high pressure tires at 107 pounds per square inch.

EFFECTS OF ARTIFICIAL OBSTRUCTIONS AND NATURAL ROAD CONDITIONS STUDIED

Artificial obstructions creating roughness conditions on an otherwise smooth pavement surface were used in making tests for the determination of the influence of the various operating factors, because such roughness conditions could be made to a uniform section having sufficient width to obviate any uncertainty regarding the contact relation between the tires and the obstruction.

Through the courtesy of the Ordnance Department, a concrete road at the Aberdeen Proving Ground, Md., was made available. This road is level throughout its length and traffic on it was controlled so that there was no interference during test runs. Steel obstruc-

TABLE 2.—*Truck and bus balloon tire load and inflation table.*[1] *Minimum inflation pressure in pounds per square inch and corresponding load capacity in pounds*

Minimum inflation pressure	Tire section and rim diameter (inches)																Minimum inflation pressure
	5.50	6.00	6.50	7.00	7.50			8.25			9.00			9.75			
	20	20	20	20	20	22	24	20	22	24	20	22	24	20	22	24	
35	1,125																35
40	**1,225**	1,300															40
45		**1,400**	1,525														45
50			**1,650**	1,775	1,925	2,075	2,225	2,100	2,350	2,500							50
55				**1,900**	**2,100**	**2,250**	**2,400**	2,325	2,575	2,725	2,650	2,900	3,050				55
60								**2,550**	**2,800**	**2,950**	2,950	3,200	3,350	3,300	3,600	3,800	60
65											**3,250**	**3,500**	**3,650**	3,600	3,900	4,100	65
70														**3,900**	**4,200**	**4,400**	70

Minimum inflation pressure	Tire section and rim diameter (inches)															Minimum inflation pressure
	10.50			11.25			12.00			12.75			13.50			
	20	22	24	20	22	24	20	22	24	20	22	24	20	22	24	
65	4,100	4,400	4,600													65
70	4,400	4,700	4,900	4,750	5,100											70
75	**4,700**	**5,000**	**5,200**	5,100	5,450	5,700	5,450	5,900	6,150							75
80				**5,450**	**5,800**	**6,050**	5,850	6,300	6,550	6,400	6,900	7,200				80
85							**6,250**	**6,700**	**6,950**	6,800	7,300	7,600	7,200	7,800	8,100	85
90										**7,200**	**7,700**	**8,000**	7,700	8,300	8,600	90
95													**8,200**	**8,800**	**9,100**	95

[1] Tire and Rim Association standard, adopted Feb. 14, 1930. Bold-face type indicates maximum recommended loads. Duals will carry twice the load of corresponding singles.

TABLE 3.—*Truck and bus high-pressure tire load and inflation table.*[1] *Minimum inflation pressure in pounds per square inch and corresponding load capacity in pounds*

Minimum inflation pressure	Tire section and rim diameter (inches)															Minimum inflation pressure
	3½	4	4½	5		6		7		8		9		10		
				20	24	20	24	20	24	20	24	20	24	20	24	
50	600															50
55	675	800														55
60	**750**	900	1,050													60
65		**1,000**	1,150	1,325	1,575											65
70			**1,250**	1,450	1,700	1,700										70
75				[2] 1,575	1,825	1,825	2,125									75
80				**1,700**	**1,950**	[3] 1,950	2,250	2,200	2,600							80
85						2,075	2,375	2,350	2,750	2,775	3,125					85
90						**2,200**	**2,500**	2,500	2,900	2,900	3,300	3,300	3,800			90
100								**2,800**	**3,200**	3,250	3,650	3,700	4,200	4,150	4,650	100
110										**3,600**	**4,000**	4,100	4,600	4,600	5,100	110
120												**4,500**	**5,000**	5,050	5,550	120
130														**5,500**	**6,000**	130

[1] Tire and Rim Association standard, adopted Jan. 12, 1927. Bold-face type indicates maximum recommended loads. Duals will carry twice the load of corresponding singles.

[2] Maximum load for 6-ply tire only.

[3] Maximum load for 8-ply tire only.

tions 200 feet apart were located on this road at the end of an 0.8 mile straightaway and were secured in place by means of countersunk screws to nuts set in the pavement, flush with the surface.

Two obstructions were used, each 1½ inches in height. One was an inclined plane 30 inches long and the other was a rectangular obstruction 12 inches wide. These obstructions are shown in Figure 3. While such obstructions are somewhat more severe than those ordinarily encountered on a well maintained pavement carrying high-speed traffic, their use in these tests was necessary in order to bring out definitely the differences between the various factors being studied. Smaller obstructions, corresponding to those used in earlier motor truck impact tests[1] were tried but it

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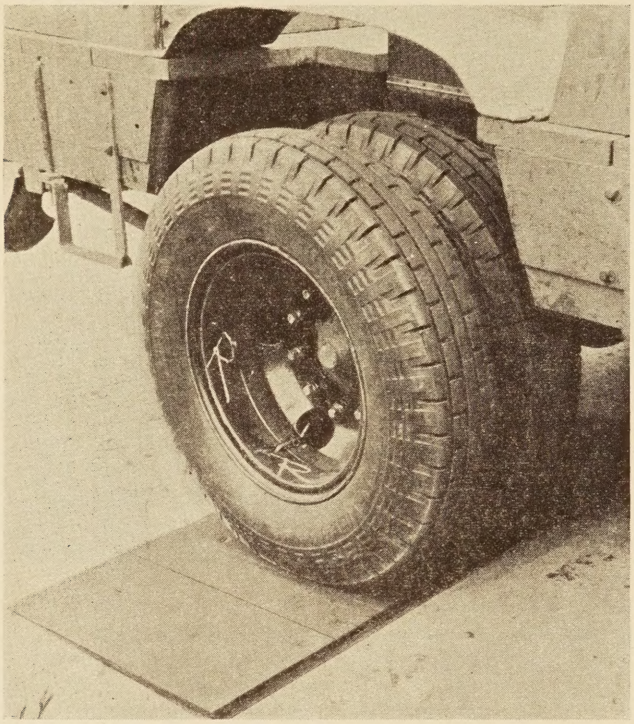
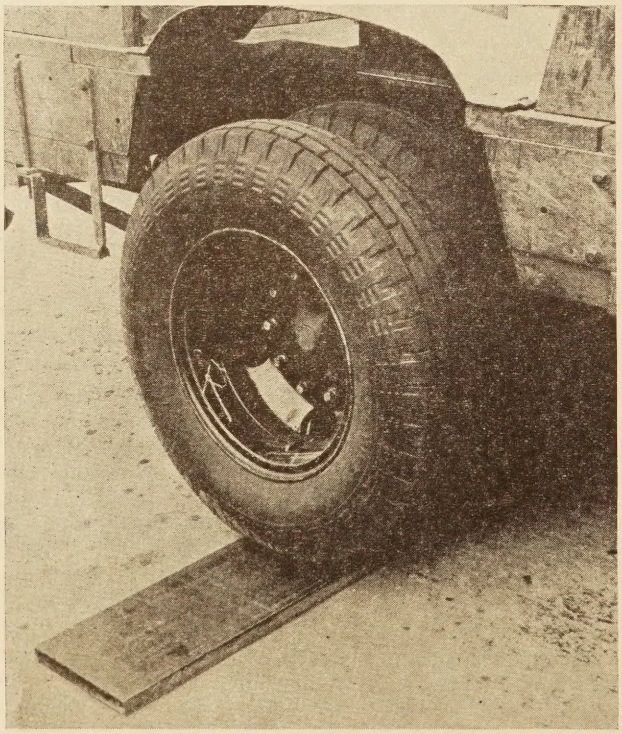
[1] These obstructions are described in an article entitled "Motor Truck Impact as Affected by Tires, Other Truck Factors and Road Roughness," Public Roads, Vol. 7, No. 4, June, 1926.

was found that the tire equipments used in these tests caused such low values of acceleration when small obstructions were encountered that differences in test conditions involving only minor changes in the factors being studied were likely to be obscured because of the dispersion due to unavoidable experimental errors.

The artificial obstructions used caused three types of impact reaction which are: (1) The drop of the wheel on the pavement after being raised by an inclined plane, (2) the shock of the wheel at striking a sharp elevation in the road, and (3) the drop of the wheel on the pavement following the shock condition just described. These obstruction conditions simulate heaved and raised joints in actual surface roughness conditions. There is probably little real difference in the action under either of the drop conditions described above other than variations in the height from which the wheel falls. In either case, the tire reacts against a plane surface. In the case of the shock reaction, there is a tendency for the obstruction to penetrate the tire or for the tire to envelop the obstruction and an entirely different situation exists.



1½ BY 30 INCH INCLINED PLANE



1½ BY 12 INCH RECTANGULAR BLOCK

Figure 3.—Road Roughness Created by Artificial Obstructions

Table 4.—*Wheel loads and other bus characteristics*

Tire size [1]	Weight wheel and tire	Unsprung weight	Unsprung mass	Load A		Load B		Load C		Load D	
				Sprung	Total	Sprung	Total	Sprung	Total	Sprung	Total
	Lbs.	*Lbs.*		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
34 x 7	350	1, 974	61. 3	4, 060	6, 034	5, 080	7, 054	6, 075	8, 049	7, 525	9, 499
38 x 7	394	2, 018	62. 7	4, 060	6, 078	------	------	------	------	------	------
9.00–20/7	380	2, 004	62. 2	4, 060	6, 064	5, 080	7, 084	6, 075	8, 079	7, 525	9, 529
9.00–24	422	2, 046	63. 5	4, 060	6, 106	5, 080	7, 126	------	------	------	------
9.00–20/8	396	2, 020	62. 7	4, 060	6, 080	------	------	------	------	------	------
9.75–20	458	2, 082	64. 7	4, 060	6, 142	------	------	6, 075	8, 157	7, 525	9, 607
10.50–20	531	2, 155	66. 9	------	------	------	------	6, 075	8, 230	7, 525	9, 680
12.00–20	335	1, 959	60. 8	4, 060	6, 019	------	------	6, 075	8, 034	------	------

Tare weights (including driver, operator, instrument, and hub spacers, with 34 by 7 inch original tire equipment):

	Pounds
Front axle	5, 720
Rear axle	7, 649
Total	13, 369

	Pounds
Unsprung weight per rear wheel	1, 962
Weight of 34 by 7 dual tires and wheel (original equipment)	338
Unsprung weight without tires and wheels	1, 624

Front axle loads:	Pounds
Load A	6, 125
Load B	6, 325
Load C	6, 700
Load D	7, 080

Front wheel loads:	Pounds
Load A	3, 062
Load B	3, 162
Load C	3, 350
Load D	3, 540

[1] These are the customary designations of the tires listed, as used by the Tire and Rim Association and by the industry in general. High pressure tires are designated by over-all height in inches and section height in inches and fractions thereof. Balloon tires are designated by section height in inches and decimals thereof and rim diameter in inches. In the case of the 9.00 by 20 inch balloons, where two rim widths were used, these are given.

Natural road surface roughness conditions were used in making tests to determine the actual magnitudes of impact forces developed under normal operating conditions. These tests were made in the vicinity of Washington, D. C., at locations where the desired speeds could be attained with safety. The natural roughness conditions which were found at places which were practicable for making tests were of less severity than the artificial obstructions described in a preceding paragraph. Profiles of the natural obstructions are given later in this report in presenting the data obtained with them.

Vertical impact reactions occurring between a moving wheel and the pavement surface may be resolved into two components. One is the dynamic force due to the vertical acceleration or deceleration imparted to the unsprung weight at the wheel and the other is the static weight on that wheel.

In the impact investigations of the bureau the dynamic force has been obtained by multiplying the value of the unsprung mass by the acceleration developed at the instant of impact. The mass values were obtained by weighing and the acceleration by measurement with an accelerometer. By adding to this dynamic force the static load on the wheel, the total vertical impact reaction was obtained and may be expressed in pound units or as a percentage of the static wheel load.[2]

MULTIPLE ELEMENT CONTACT ACCELEROMETER USED TO MEASURE IMPACT FORCES

The multiple element contact accelerometer used in these tests was designed and built by the Bureau of Public Roads as a modification of a single element instrument of the same type described in the July, 1930, issue of Public Roads. It differs from the original instrument in that it comprises 10 sensitive elements equipped with styli for direct recording on a moving ribbon of paraffin-coated colored paper. The hardened steel styli have ball points and the elements are arranged in offset relation so that the record made by one element does not interfere with that made by another. The movement of each sensitive element measured at its center of gravity was restricted to 0.001 inch between the recording and non-recording positions of its stylus. The accelerometer was mounted on the rear axle of the bus, the frame supporting it being clamped securely to the top of the right hand spring bolster by the bolts which held the spring to the axle. It was thus in a position to respond to any vertical accelerations imparted to the axle by the wheel. A general view of the instrument is given in Figure 4.

The sensitive elements were calibrated statically and dynamically according to methods described in the earlier publication.[3] As the dynamic calibration involved the use of a telephone circuit to detect movement of the sensitive elements, additional tests were made to prove that the autographic recording on paraffin-coated paper is as accurate and reliable as that involving the telephone circuit. A further check on the calibration was obtained by comparing the experimental values with the design or theoretical values. The characteristics of the 10 elements used are given in Table 5.

TABLE 5.—*Characteristics of accelerometer elements*

Element No.	Thickness of spring	Calibration rate	Free period
	Inches	*Feet per sec.*^{2} *per 0.001 inch deflection* [1]	*Seconds*
1	0.0381	2.79	0.0071
2	.0402	3.26	.0067
3	.0410	3.52	.0066
4	.0425	3.85	.0063
5	.0437	4.26	.0062
6	.0451	4.53	.0060
7	.0458	4.72	.0059
8	.0470	5.00	.0057
9	.0480	5.48	.0056
10	.0491	5.78	.0055

[1] Measured at the micrometer.

Accelerometers of the contact type are so designed that the action of any one sensitive element will only indicate whether an acceleration greater or less than a certain magnitude was attained during impact. That critical acceleration magnitude is determined by the resistance to be overcome (which, in the accelerometer used is caused by the deflection of a cantilever spring) and the mass of the sensitive element acted upon by the impressed acceleration. By placing a battery of such elements in a single instrument unit and setting each element to respond to a different magnitude of acceleration, an impressed acceleration may be determined as lying between certain limits which are indicated by the critical values of the elements which do or do not respond. In the tests herein described, the critical accelerations to which the various elements were set to respond varied in increments of 10 feet per second per second, and the range in acceleration thus covered by the instrument unit at any one time was, therefore, 90 feet per second per second.

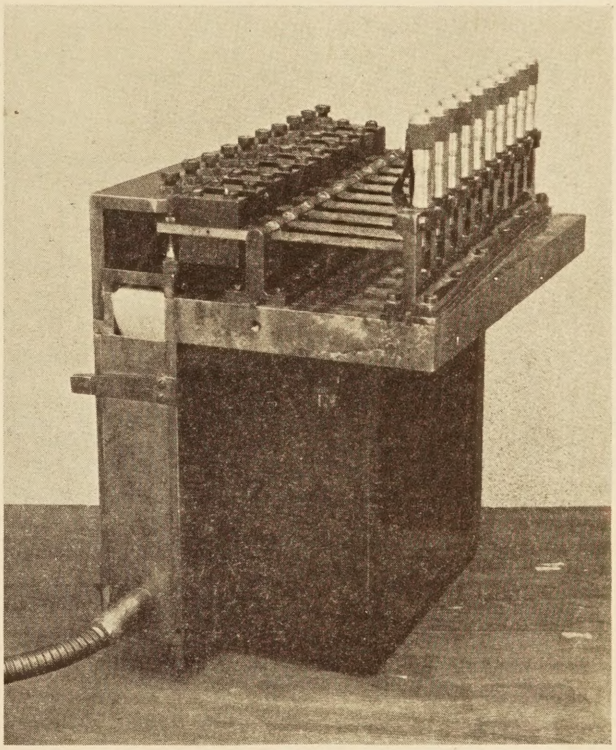


FIGURE 4.—THE AUTOGRAPHIC MULTIPLE-ELEMENT CONTACT ACCELEROMETER

If the acceleration attained in a given impact test did not fall within the range covered, as indicated by the fact that all the elements responded or failed to respond, that test was repeated with the elements set to include a higher or lower group of critical accelerations as the case might be. If some of the elements responded, Nos. 1 to 3 by way of example, and the remainder, Nos. 4 to 10, did not respond, then the acceleration for that test was determined as lying between the critical values for which elements Nos. 3 and 4 had been set. It frequently happened that when the instrument was set to record the acceleration produced by one of the two artificial obstructions it would also respond to that produced by the other. Thus one acceleration might be determined by elements 3 and 4 and the other by elements 8 and 9. In this manner an opportunity was afforded to check the result thus obtained by chance with that obtained when the instrument was set to record the acceleration produced by the other obstruction. The checks thus obtained were always very close.

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[2] To be strictly accurate, some allowance should be made for the variation in pressure transmitted through the vehicle spring as it flexes during the impact phenomenon. This had been determined in earlier tests (see Public Roads, Vol. 7, No. 4, June, 1926) and found to exert comparatively little influence. Since comparative tests would all be slightly modified by approximately equal amounts, the determination, by measurement, of variations in spring pressure was not considered to be justified in this series of tests.

[3] See Public Roads, July, 1930.

DISCUSSION OF THE DATA

Typical curves showing results obtained with the artifical obstructions are given in Figure 5. It is noted that where drop conditions exist a maximum reaction is reached at a comparatively low speed and that the reaction generally decreases as the speed is increased above this critical value. The interaction between the sprung and unsprung weights of the vehicle while the wheel is in the air and falling is probably the reason for this condition.

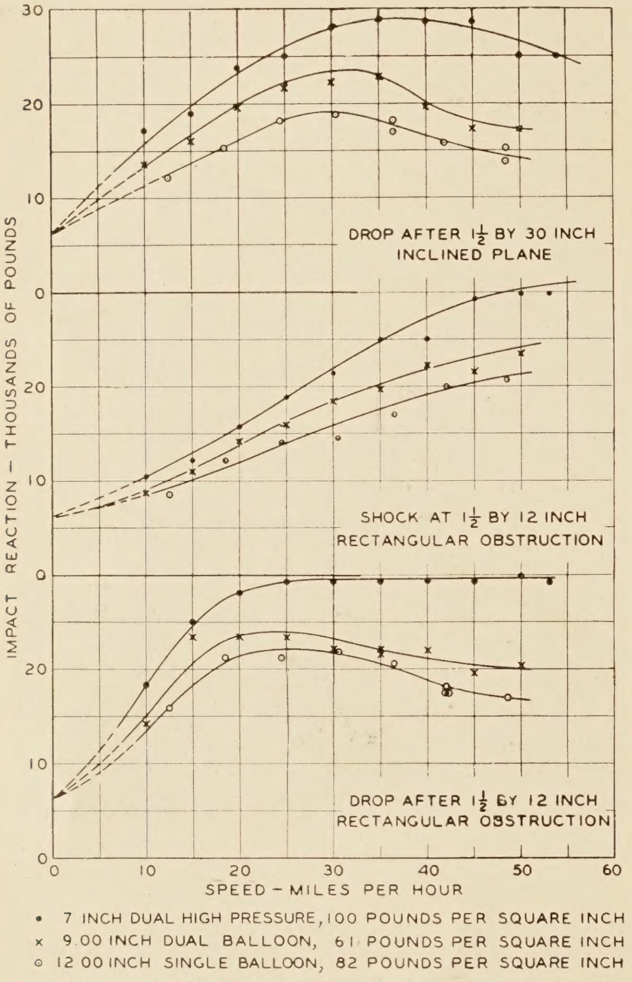

Figure 5.—Impact Reactions for Typical Tire Equipments Passing Over the Artificial Obstructions

The reactions under shock conditions are found to increase in approximate proportion with vehicle speed. When the wheel encounters an obstruction under shock conditions, there is a tendency for it to be raised above the surface of the road. As the vehicle speed increases this elevation must necessarily take place in a shorter time interval, resulting in greater vertical accelerations with corresponding increases in impact reaction. The maximum reaction obviously occurs when a given obstruction causes a maximum deformation in the tire. It is reasonable to suppose that this maximum deformation occurs when the tire completely envelops the obstruction without appreciably increasing the elevation of the axle. An approach to this maximum condition is noted in the tendency for the curves to flatten at higher speeds, indicated in the central section of Figure 5.[4]

The two lower sections of Figure 5 are for shock at and drop after a given obstruction. It is noted that the values of the drop reactions obtained at relatively low speeds are not equaled or exceeded by the corresponding shock reactions except at relatively high vehicle speeds. For the particular vehicle and other test conditions given these speeds are from 20 to 30 miles per hour for the maximum drop reaction and 50 to 60 miles per hour for shock reactions of equal magnitude.

BALLOON TIRE EQUIPMENT REDUCES IMPACT REACTIONS

One of the questions most frequently asked is, "What is the relative influence of the type of tire equipment on impact reaction?" In Figure 5, data are given for three types of impact reaction, comparing the forces produced on the pavement by the same wheel when equipped with dual high pressure pneumatic, dual balloon, and single balloon tires of equal capacity and carrying the same load. There is no question as to the additional protection to the road which results from replacing high pressure pneumatic tires with balloon tires. The balloon tire operates at a lower inflation pressure and has a greater section height than the high pressure tire of equal capacity, both of which factors enhance its cushioning properties. Since protection to the road is also protection to the vehicle this comparison has a major economic significance. The road strikes the vehicle wheel just as severely as the wheel strikes the road.

SINGLE BALLOON TIRE PRODUCES LOWER IMPACT FORCES THAN CORRESPONDING DUAL MOUNTING, BUT GREATER CONCENTRATION OF PRESSURE RESULTS

The relation between dual and single tire equipments of the same type and of equal load carrying capacity is also brought out in Figure 5. Although the 12.00-inch balloon requires an inflation pressure of 82 pounds per square inch as compared with 61 pounds per square inch required for dual 9.00-inch tires to carry the same load, the greater section height of the single tire results in lower impact forces than those caused by the smaller-sectioned dual tires. This observation supports a similar conclusion reached as a result of the earlier impact tests with motor trucks and reported in the June, 1926, issue of Public Roads.

In connection with this discussion of dual versus single tire equipments, it is important to consider the intensity of contact pressures developed by the two types. As shown by Table 6, which gives results obtained from static tests on the three equipments involved in Figure 5, the single balloon tire develops considerably higher average contact pressures than do the dual balloon tires. The data given in Table 6 are based on measurements of contact area and contact width as given by the three tire types under static loads.

The static load-deflection characteristics of the three tire equipments discussed above are given in Figure 6,

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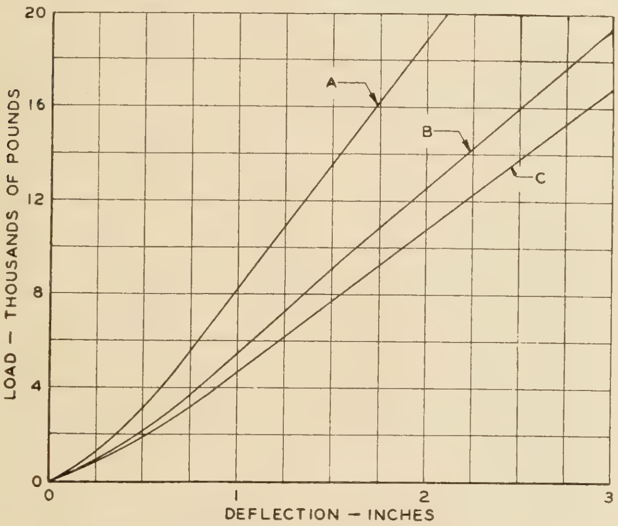
[4] In the article entitled "Calibrations of Accelerometers for Use in Motor Truck Impact Tests," Public Roads, Vol. 11, No. 5, July, 1930, the nature of the shock reaction is discussed from a theoretical standpoint. It is believed that the theory developed, although the assumptions on which it is based are admittedly approximate, indicates, qualitatively, the influence of the several variables involved in the shock impact. On the basis of this theory the limiting value of the shock reaction is given by the equation, $F=L+Kh$, where L is the wheel load, K is a factor expressing the resistance of the tire to the vertical deformation caused by the obstruction, and h is the height of the obstruction.

TABLE 6.—*Comparison of contact pressures developed by dual high pressure, dual balloon, and single balloon tires*

Tire size	Inflation pressure	Load per wheel	Unit pressure, based on gross contact area	Average load per unit contact width
Inches	*Lbs. per sq. in.*	*Pounds*	*Lbs. per sq. in.*	*Lbs. per in.*
Dual 34 by 7	100	6,000	86	581
		12,000	103	1,012
		18,000	118	1,488
Dual 9.00 by 20	61	6,000	59	485
		12,000	75	936
		18,000	85	1,353
Single 12.00 by 20	82	6,000	76	761
		12,000	90	1,264
		18,000	101	1,811

for purposes of comparison. It is at once apparent that, for comparable operating conditions, the relation between the static load-deflection characteristics of the tires is a fair index of the relative impact reactions produced by them.



A- 7 INCH DUAL HIGH PRESSURE, 100 POUNDS PER SQUARE INCH
B- 9.00 INCH DUAL BALLOON, 61 POUNDS PER SQUARE INCH
C-12.00 INCH SINGLE BALLOON, 82 POUNDS PER SQUARE INCH

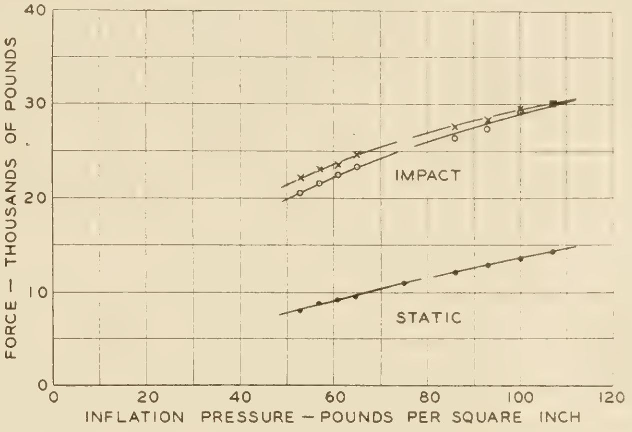
FIGURE 6.—STATIC LOAD-DEFLECTION CURVES SHOWING INFLUENCE OF TIRE TYPE

VARIATION OF IMPACT FORCE WITH INFLATION PRESSURE ANALYZED

Closely related to the influence of tire type is that of inflation pressure. It was noted in the discussion of Figure 5 that maximum reactions were obtained at relatively low speeds for the drop impact conditions. In Figure 7 the magnitudes of these maximum reactions have been plotted against corresponding variations in inflation pressures and curves have been drawn for the two drop impact conditions. The wheel load was 6,000 pounds in each case and the speed was that at which the maximum drop reaction occurred. The curves have been broken between points representing the two tire equipments represented by these data, the higher inflation pressures having been applied to dual 34 by 7 inch high-pressure tires and the lower pressures to dual 9.00 by 20 inch balloon tires, the two tire equipments being replacement sizes for each other. It is at once noted that the variation in maximum impact reaction is approximately proportional to the variation in inflation pressure.

For purposes of comparison, the static reactions corresponding to a deflection of 1½ inches have also been plotted against the corresponding inflation pressures in Figure 7. The analogy between relations brought out by static and impact tests is again apparent.

The influence of inflation pressure is brought out in a different way in Figure 8. In this figure, which involves the three types of impact reaction, data are plotted for all tire equipments which were tested under the load and inflation standards set forth in Tables 2 and 3. The curves which have been drawn may be regarded as typical for high pressure and balloon tires under the respective roughness conditions involved. In this figure the mean ratio of the dynamic increments (i. e., ordinates above the 100 per cent static load line) for balloon tires to the corresponding increments for high pressure tires is about 0.62; while the mean ratio of the total impact reactions is about 0.72. The mean ratio between the inflation pressures recommend in Table 2 to carry a given load on balloon tires and those recommended in Table 3 for high-pressure tires of equal base (rim) diameter at the same load was found to be about 0.63. It may, therefore, be concluded that, for a given roughness condition and at a given speed, balloon and high-pressure tire equipments will develop impact reactions, in excess of static load, approximately in the proportion of the inflation pressures used, where the load carried is the same in each case and recommended inflation pressures are used. According to current standards this proportion is of the order of two to three.



DROP IMPACT REACTIONS:—
× MAXIMUM AFTER PASSING 1½ BY 12 INCH OBSTRUCTION
○ MAXIMUM AFTER PASSING 1½ BY 30 INCH INCLINED PLANE
STATIC REACTION:—
● LOAD WHEN TIRES ARE DEFLECTED 1½ INCHES

FIGURE 7.—INFLUENCE OF INFLATION PRESSURE ON TIRE REACTIONS

EFFECT OF LOAD STUDIED

In Figures 9 to 13, data are given which show the influence of load on impact reaction. The three sections in each figure refer to the three types of reaction caused by the artificial obstructions. In Figures 9 and 10, impact forces have been expressed in pound units and in Figures 11 and 12 they have been plotted as a percentage of the particular wheel load carried. In these tests, the inflation pressure in a given tire was maintained constant as the load was varied, 100 pounds per square inch being applied to the dual 34 by 7 inch high-

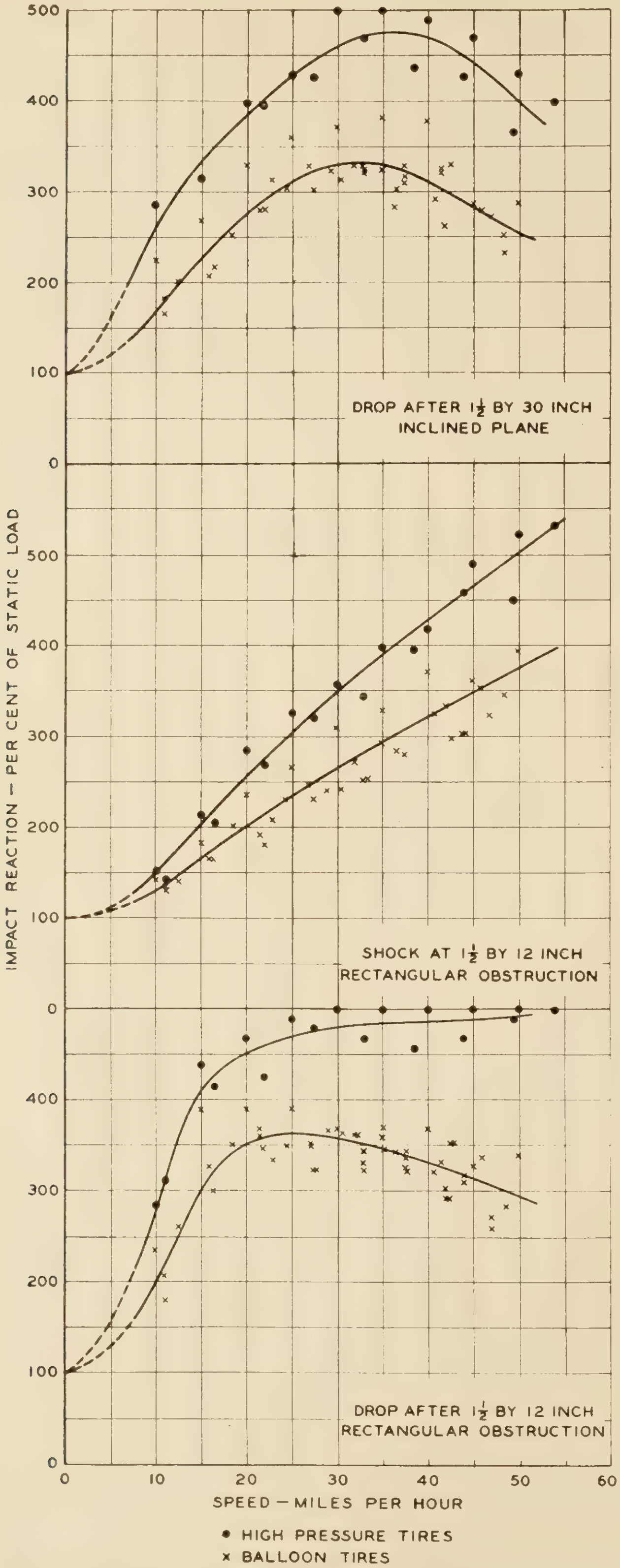


Figure 8.—Balloon Versus High-Pressure Tires: Impact Reactions Produced by Artificial Obstructions for All Tire Equipments Tested at Recommended Loads and Inflation Pressures

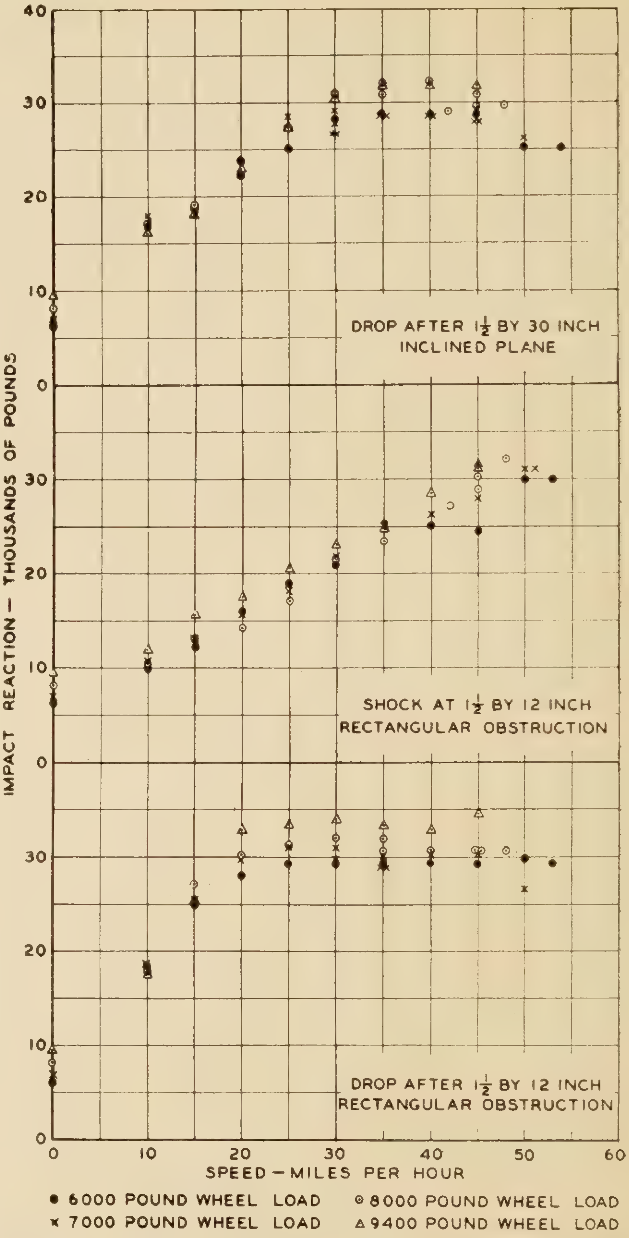


Figure 9.—Influence of Load on the Impact Reactions Produced by Dual 34 by 7 Inch High-Pressure Tires at an Inflation Pressure of 100 Pounds per Square Inch. Plotted Points Denote Values of the Impact Reactions in Thousands of Pounds

pressure pneumatics and 65 pounds per square inch to the dual 9.00 by 20 inch balloons. In Figure 13, comparisons are made between tire equipments seriously overloaded and larger equipment designed to carry such loads.

For the test conditions covered by Figures 9 and 10, it is noted that load has comparatively little influence on the magnitude of the impact reaction between the wheel and the pavement. The heavier loads have some slight tendency toward increased reactions, but this increase scarcely exceeds the difference in static wheel load. It is indicated that, within the load range of these tests, the dynamic increment, i. e., the increase in force above that due to static load, is approximately constant for a given tire and inflation condition and for stated speed and roughness conditions.

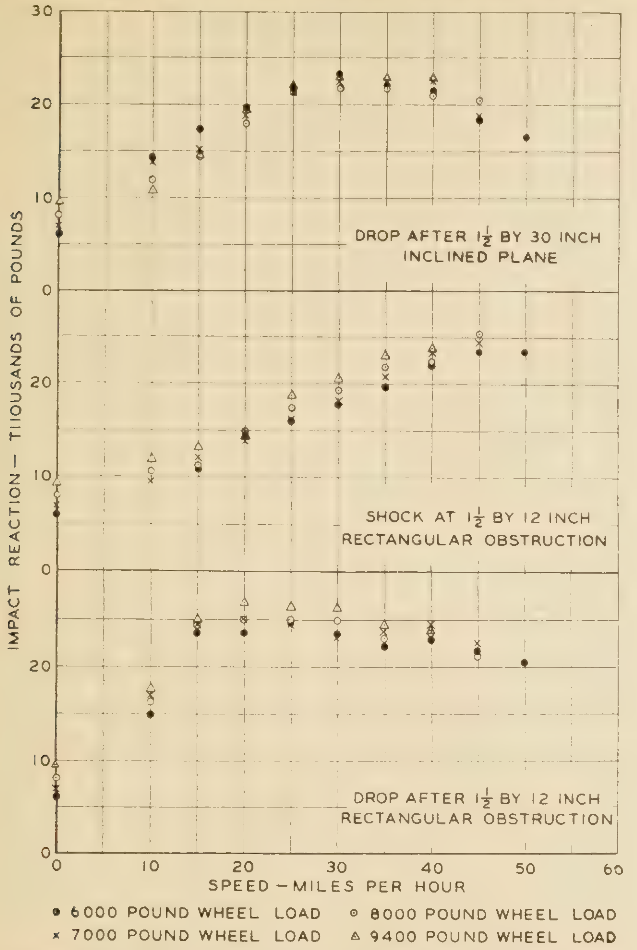


Figure 10.—Influence of Load on the Impact Reactions Produced by Dual 9.00 by 20 Inch Balloon Tires at an Inflation Pressure of 65 Pounds per Square Inch. Plotted Points Denote Values of the Impact Reaction in Thousands of Pounds

In Figures 11 and 12, the impact reactions corresponding to those in Figures 9 and 10 have been plotted on the basis of their percentage of the static wheel loads used. It is at once noted that on this basis and for the conditions covered by these tests there is a marked decrease as the wheel load is increased. These indications which are so clearly brought out in Figures 9 to 12 are in accordance with those previously observed in the report on motor truck impact tests in the June, 1926, issue of Public Roads.

In Figure 13 the reactions obtained with dual 10.50 by 20 inch balloons which are designed to carry a wheel load of 9,400 pounds at the recommended inflation pressure of 75 pounds per square inch are compared with the reactions obtained with dual 34 by 7 inch high-pressure tires at 100 pounds per square inch and dual 9.00 by 20 inch balloon tires at 65 pounds per square inch, each of the two latter being overloaded approximately 50 per cent to carry the 9,400-pound wheel load. In the earlier experiments [5] the conclusion was reached that, for a given type of tire equipment, a smaller size operating overloaded causes lower reactions than a larger size operating at that same load. Referring to Figure 13, we confirm this conclusion as applying to the balloon type, lower reactions being caused by the overloaded 9.00 by 20 inch tires than are by the properly loaded 10.50 by 20 inch tires, the same wheel load being carried in each case.

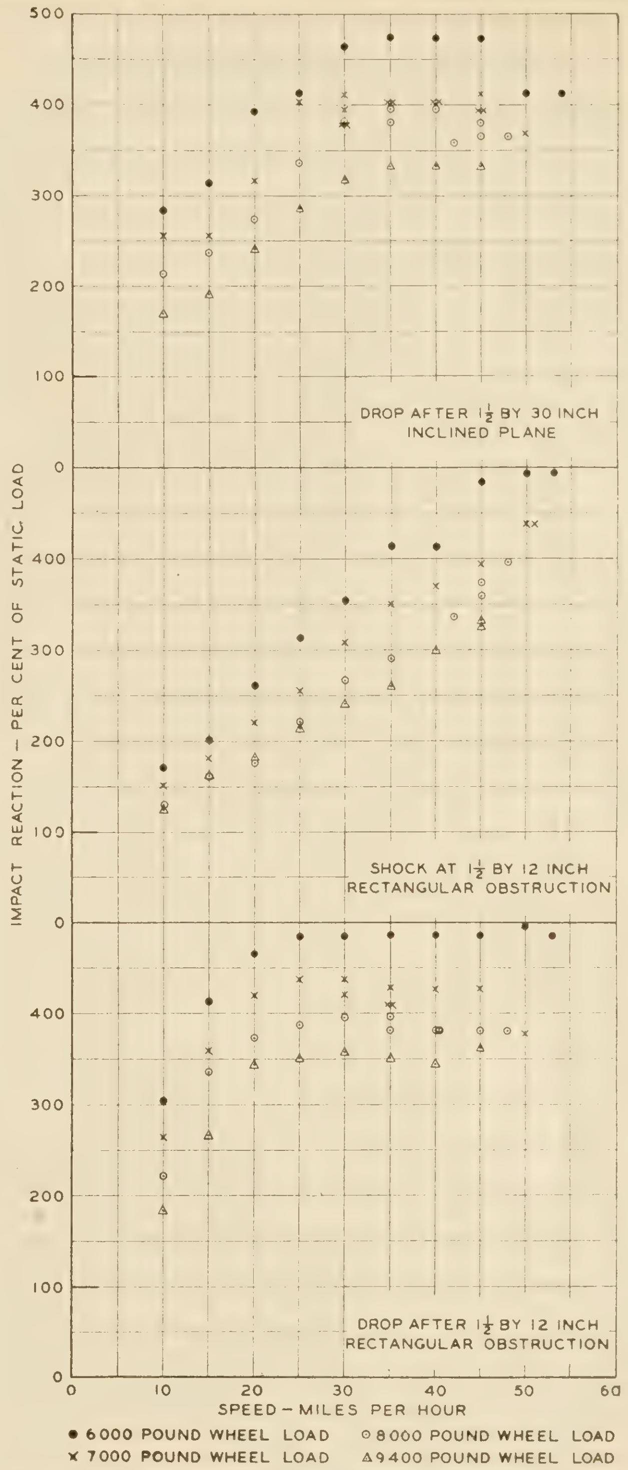


Figure 11.—Influence of Load on the Impact Reactions Produced by Dual 34 by 7 Inch High-Pressure Tires at an Inflation Pressure of 100 Pounds per Square Inch. Plotted Points Denote Values of the Impact Reaction in Percentage of Static Load

In a preceding paragraph it was brought out that impact reactions are approximately in proportion to the inflation pressure used in a pneumatic tire. It should therefore be expected that balloon tires would cause lower reactions than comparable high-pressure tires having the same load-carrying capacity, since the balloon tires operate at considerably lower inflation pressures. This is borne out in Figure 13, the 9.00 by 20 inch tires causing lower reactions than the 34 by 7 inch tires under the same load conditions.

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[5] See Public Roads, June, 1926.

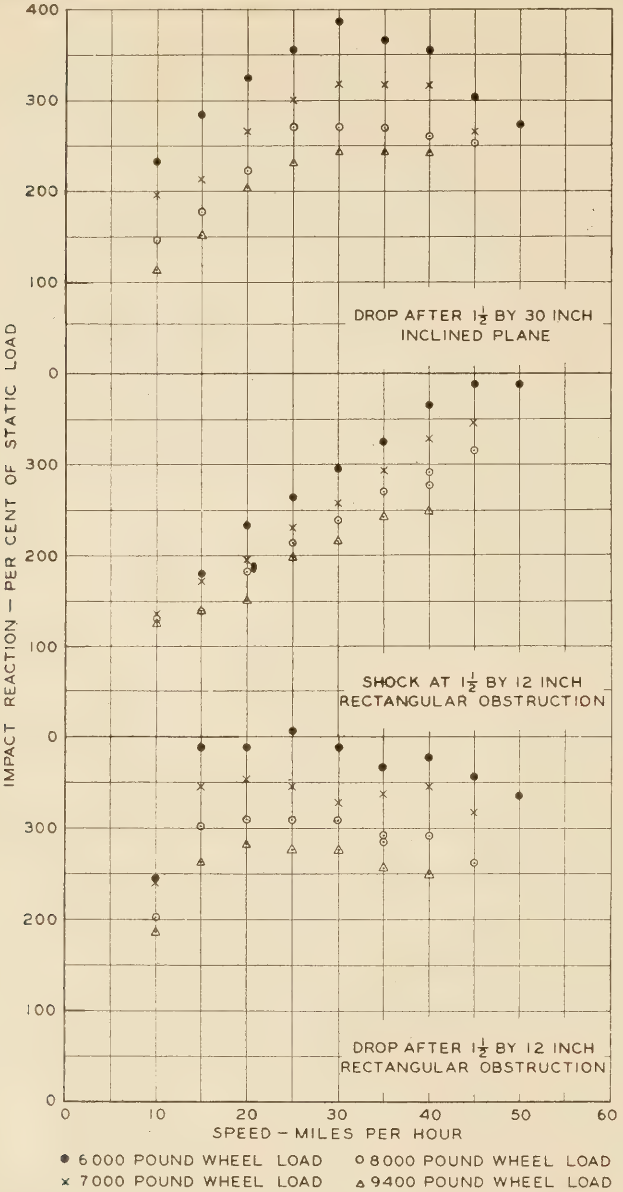

Figure 12.—Influence of Load on the Impact Reactions Produced by Dual 9.00 by 20 Inch Balloon Tires at an Inflation Pressure of 65 Pounds per Square Inch. Plotted Points Denote Values of the Impact Reaction in Percentage of Static Load

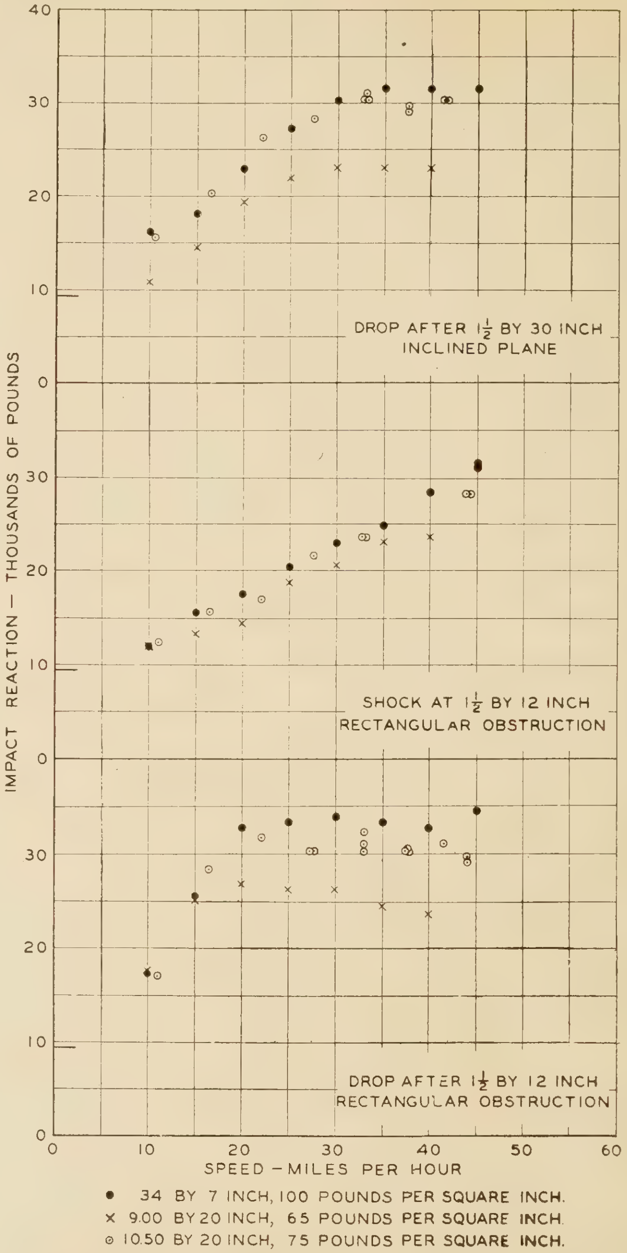

Figure 13.—Comparison of the Impact Reactions Produced by Wheels Loaded to 9,400 Pounds and Equipped Respectively, with Overloaded 34 by 7 Inch High-Pressure Tires, Overloaded 9.00 by 20 Inch Balloon Tires, and Normally Loaded 10.50 by 20 Inch Balloon Tires, all Dual Mountings

It has just been shown that the 9.00 by 20 inch overloaded balloon tires cause lower reactions than either the 10.50 by 20 inch normally loaded balloon tires or the 34 by 7 inch overloaded high-pressure tires, the same wheel loads being carried by each. It is interesting to note in Figure 13 that the reactions caused by the 34 by 7 inch high-pressure tires and those caused by the 10.50 by 20 inch balloon tires were approximately the same. It appears, then, that for the tire equipments and other test conditions involved the overloaded 9.00 by 20 inch balloon tires caused lower reactions than the properly loaded 10.50 by 20 inch balloon tires in about the same degree that the overloaded balloon type caused lower reactions than the overloaded high-pressure type.

The impression should not be given from the data in Figures 9 to 13 that overloading is a practice to be cultivated. While it is true that lower magnitudes of impact reaction are obtained with overloaded tires than when tires of adequate capacity are used, other factors should be considered. One factor which is of particular importance to highway engineers is the increased intensity of road contact pressure which results from overloading. Table 7, based on static tests, gives average loads per unit of gross area of contact and per unit of width of contact for the three tire equipments under consideration. The increased concentration due to overloading is apparent.

Another factor to be considered before overloading is permitted is the decrease in tire mileage under operating conditions involving heavier loads than those for which tires are designed. According to statements of tire manufacturers, the practice of loading tires to 150 per cent of their recommended capacities results

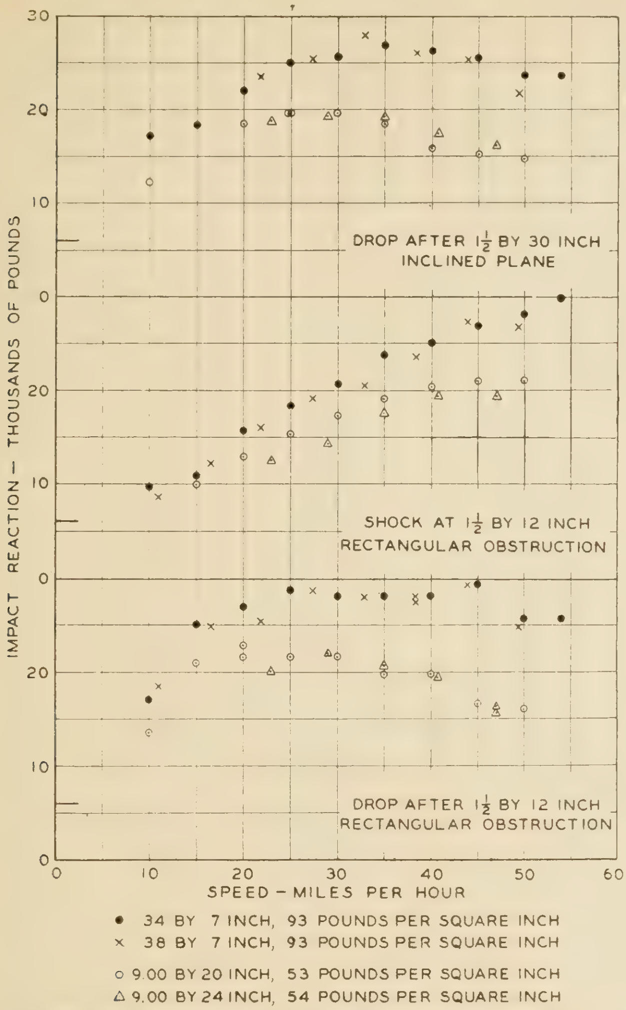

FIGURE 14.—INFLUENCE OF RIM DIAMETER ON THE IMPACT REACTIONS PRODUCED BY HIGH PRESSURE AND BALLOON TIRES, THE TWO TIRES OF EACH TYPE BEING INFLATED TO THE SAME PRESSURE. WHEEL LOAD, 6,000 POUNDS

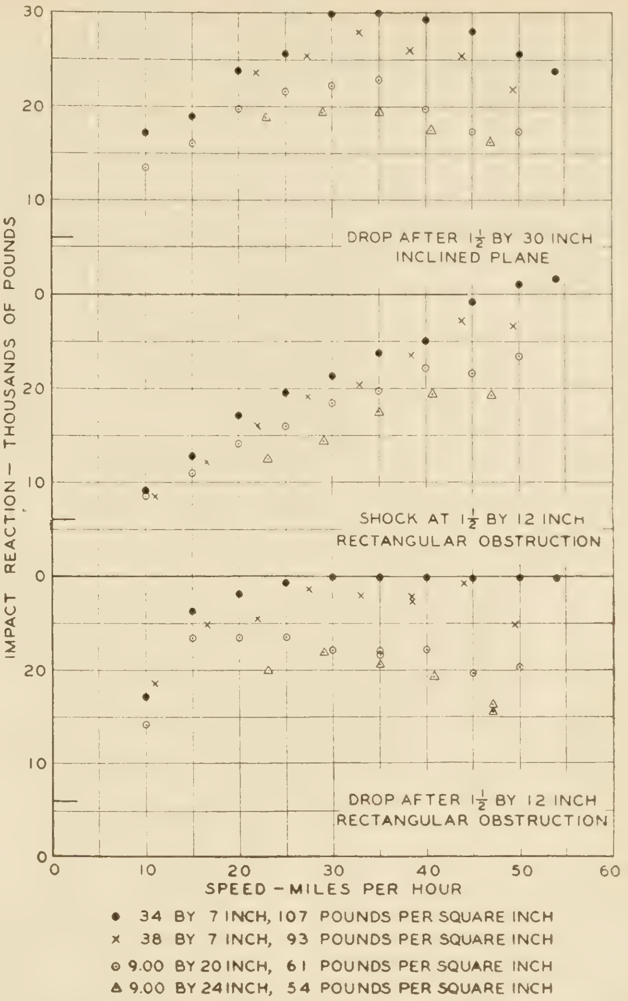

FIGURE 15.—INFLUENCE OF RIM DIAMETER ON THE IMPACT REACTIONS PRODUCED BY HIGH-PRESSURE AND BALLOON TIRES, EACH TIRE BEING INFLATED TO ITS RECOMMENDED PRESSURE. WHEEL LOAD, 6,000 POUNDS

in a decrease of approximately 50 per cent in the mileage they would be expected to give in normal service.

EFFECT OF RIM DIAMETER NEGLIGIBLE IF INFLATION PRESSURES ARE EQUAL

The influence of rim diameter on impact reactions produced by tires of a given sectional size is given in Figures 14 and 15. Most, if not all, of the high-pressure and balloon tires in truck and bus service in this country to-day are for appliance on rims having diameters of 20, 22, or 24 inches. This results in a variation in rolling radius of approximately two inches for a given sectional size of tire. In Figure 14 are given the reactions obtained with 7-inch high-pressure and 9.00-inch balloon sections applied to 20 and 24 inch diameter rims, the inflation pressure being 93 pounds per square inch for the 7-inch sections and 53 to 54 pounds per square inch for the 9.00-inch sections. It may be stated that, within the scope of these tests, there is no important difference in impact reaction between tires of a given cross-section but differing by 4 inches in diameter, when the inflation pressures are equal.

TABLE 7.—*Comparison of contact pressures developed by 34 by 7 inch high pressure, 9.00 by 20 inch balloon, and 10.50 by 20 inch balloon tires, under equal loads*

Tire size	Inflation pressure	Load per tire	Unit pressure, based on gross contact area	Average load per unit contact width
Inches	*Lbs. per sq. in.*	*Pounds*	*Lbs. per sq. in.*	*Lbs. per in.*
34 by 7	100	[1] 3,000	86	581
		4,700	[2] 96	[2] 825
		6,000	103	1,012
		9,000	118	1,488
		9,400	[3] 120	[3] 1,550
9.00 by 20	65	[1] 3,000	62	498
		4,700	[2] 72	[2] 750
		6,000	78	933
		9,000	89	1,360
		9,400	[3] 90	[3] 1,420
10.50 by 20	75	[1] 4,700	78	711
		9,400	88	1,124
		14,100	100	1,621

[1] Approximate capacity load. [2] Interpolated. [3] Extrapolated

Referring back to Tables 2 and 3, we note that the recommended inflation pressure for tires of a given section to carry a given load is less for those mounted on larger diameter rims than for those mounted on smaller diameters. In Figure 15, another comparison is made of the reactions caused by 7-inch high-pressure and 9.00-inch balloon tires on 20 and 24-inch rims. The data here presented were obtained from tests in which each tire carried the recommended pressure for the given load. In this case the reactions involving the larger rim diameter are noticeably less than those involving the smaller, and taken in conjunction with the study of Figure 14, this decrease may be largely attributed to the lower inflation pressures used with the larger diameter tires.

The static load-deflection curves given in Figure 16 support the impact reaction data given in Figures 14 and 15. Here again it is noted that where the pressure is the same there is but little difference between the behavior of tires of a given section but of different diameters.

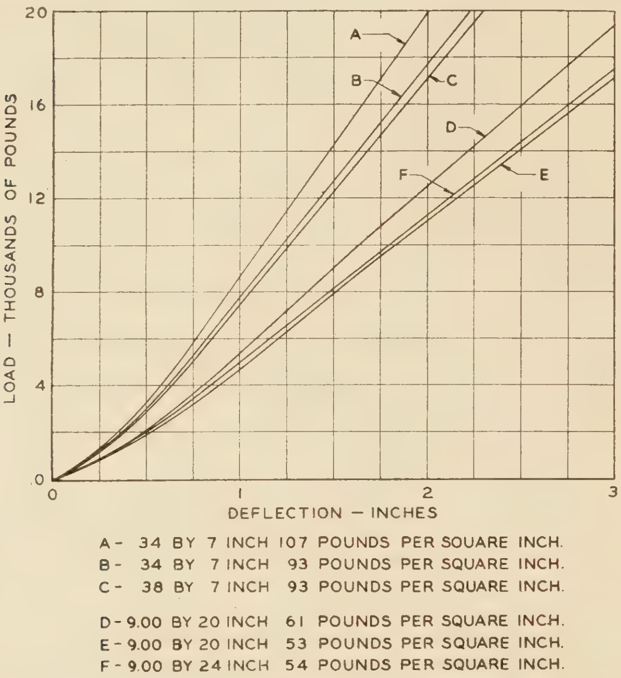

FIGURE 16.—STATIC LOAD-DEFLECTION CURVES SHOWING THE INFLUENCE OF RIM DIAMETER ON HIGH-PRESSURE AND BALLOON TIRES

VARIATION IN RIM WIDTH HAS NO APPRECIABLE INFLUENCE

It frequently happens that a given tire may properly be applied to rims of different widths. For instance, if the original tire equipment on a vehicle were 34 by 7, 7.50 by 20, or 8.25 by 20 inch, the original rim equipment would be 20 by 7 inch. Should it be desirable to use 9.00 by 20 inch tires on that vehicle, accepted practice would permit the application of such tires to the 20 by 7 inch rims provided other factors such as clearance and gear ratio did not interfere. However, if the vehicle had been originally equipped with 36 by 8 or 9.00 by 20 inch tires the rim equipment would have been 20 by 8 inch. The inflation pressure recommended for the 9.00 by 20 inch tires would be the same whether mounted on either rim.

The impact reactions obtained with dual 9.00 by 20 inch tires mounted on 7 and 8 inch rims are given in Figure 17 and the corresponding static load-deflection curves are in Figure 18. It is at once apparent that this variation of one inch in rim width causes no appreciable change in the action of the tires.

COMPARISONS MADE WITH DATA FROM EARLIER TRUCK IMPACT TESTS

At this point it would be well to compare the impact reactions obtained in these tests with the bus chassis at relatively high speeds with those obtained in the earlier tests with trucks at relatively low speeds. In both series of tests an inclined plane artificial obstruction 1½ inches in height and 30 inches in length was involved. For this roughness condition and for comparable tires and loads, results from the bus and truck tests have been plotted in Figures 19, 20, and 21. The data concerning trucks in Figures 19 and 20 were obtained from tests made with a 3-ton chassis with 6,000 and 7,000 pound wheel loads, respectively; while in Figure 21 they concern 8,400-pound wheel loads on a 5-ton chassis. In the bus tests the same chassis was used for all loads.

The impact reactions for the truck tests were computed by the method allowing for variations in truck spring pressure (see Public Roads, June, 1926), while in the bus tests a constant pressure equal to the pressure at static load was used in computation. Although relations between variable factors are adequately brought out by either computation method, the truck data were recomputed according to that used in the bus tests in order that the comparisons herein presented might be as nearly as possible on the same basis. It might also be mentioned here that the truck data were taken by an accelerometer which acted on a different principle than that which was used in the bus tests, it being the coil spring instrument, the calibration of which was described in the July, 1930, issue of Public Roads.

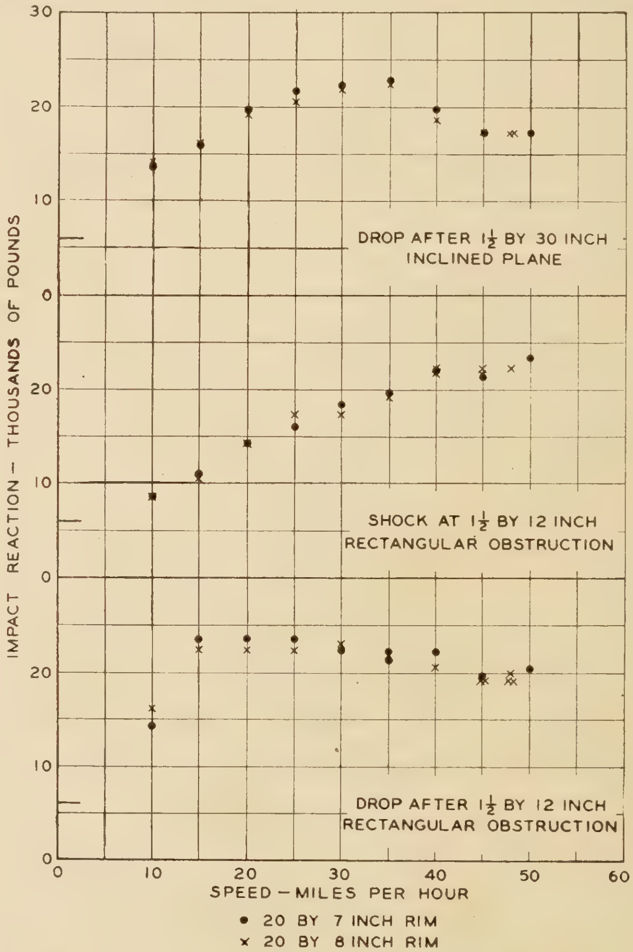

FIGURE 17.—INFLUENCE OF RIM WIDTH ON THE IMPACT REACTIONS PRODUCED BY DUAL 9.00 BY 20 INCH BALLOON TIRES. WHEEL LOAD 6,000 POUNDS; INFLATION PRESSURE, 61 POUNDS PER SQUARE INCH

In Figure 19 the wheel load involved in each case was 6,000 pounds and the tire equipments were all loaded to capacity. The data for balloon tires at an inflation pressure of 61 pounds per square inch were

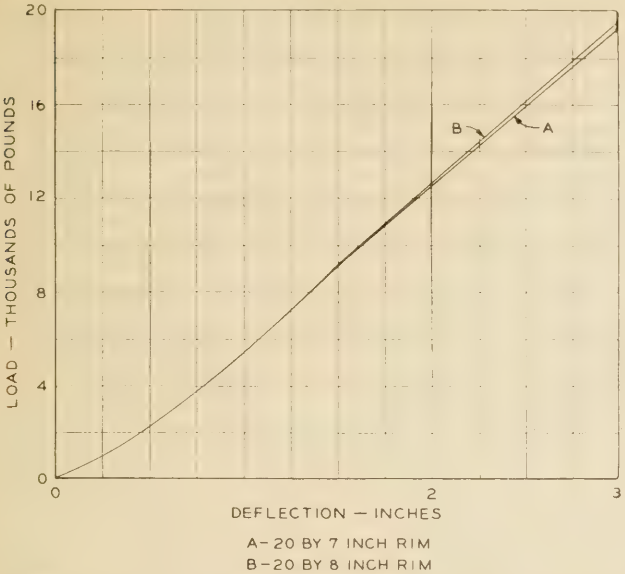

FIGURE 18.—STATIC LOAD-DEFLECTION CURVES SHOWING THE INFLUENCE OF RIM WIDTH ON A 9.00 BY 20 INCH BALLOON TIRE. INFLATION PRESSURE, 61 POUNDS PER SQUARE INCH

taken with dual 9.00 by 20 inch tires on the bus chassis. The data for high-pressure pneumatic tires at an inflation pressure of 100 pounds per square inch were taken with dual 34 by 7 inch tires on the bus chassis and with dual 38 by 7 inch tires on a 3-ton truck chassis as indicated in the figure. It is worthy of note that these data from independently conducted tests involving different vehicles and different instruments are in such close agreement. The data for new and worn solid tires were taken with dual 36 by 5 inch tires on the 3-ton truck chassis, the thickness of rubber visible above the tire flange being a little over 2 inches for the new tires and averaging a little less than 1 inch for the worn tires.

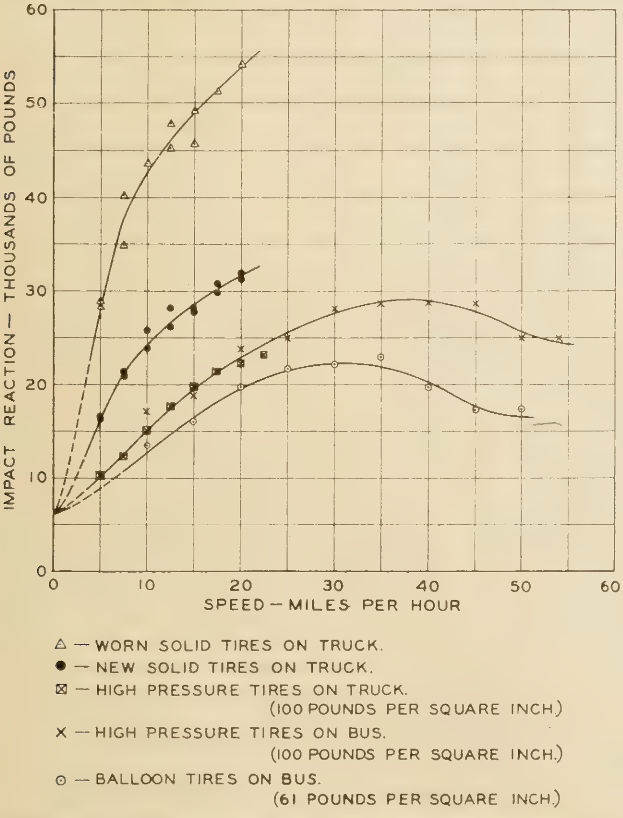

FIGURE 19.—COMPARISON OF DATA FROM SEPARATELY CONDUCTED TRUCK AND BUS IMPACT TESTS, SHOWING REACTIONS PRODUCED BY VARIOUS TYPES OF TIRE EQUIPMENT. PLOTTED POINTS DENOTE IMPACT REACTIONS CAUSED BY DROP AFTER 1½ BY 30 INCH INCLINED PLANE

The wheel load used in the comparison shown in Figure 20 was 7,000 pounds, the tires being loaded to capacity in each case. The balloon tires at an inflation pressure of 63 pounds per square inch were the dual 9.00 by 24 inch tires on the bus chassis and the new cushion tires were dual 36 by 7 inch on the 3-ton truck chassis. The cushion tires included three brands and the average thickness of visible rubber beyond the tire flange was 3³⁄₁₆ inches.

The tire equipments compared in Figure 21 were also tested at capacity loads. The data for balloon equipment were obtained with the bus chassis using dual 10.50 by 20 inch tires inflated to 75 pounds per square inch at which pressure the wheel load capacity was 9,400 pounds. The new and worn solid tires were tested at a wheel load of 8,400 pounds, using a 5-ton truck chassis. They involved dual 40 by 6 inch and single 40 by 12 inch tires of each type, the average thickness of rubber on the new solid tires being about two and one-half inches visible above the flange of the rim and about three-fourths inch in the case of the badly worn solid tires.

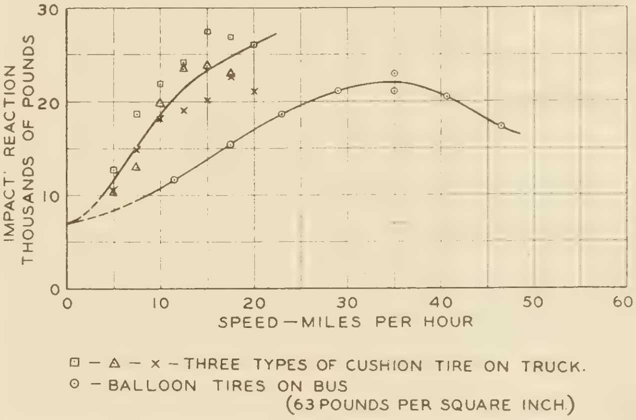

FIGURE 20.—COMPARISON OF DATA FROM SEPARATELY CONDUCTED TRUCK AND BUS IMPACT TESTS, SHOWING REACTIONS PRODUCED BY VARIOUS TYPES OF TIRE EQUIPMENT. PLOTTED POINTS DENOTE IMPACT REACTIONS CAUSED BY DROP AFTER 1½ BY 30 INCH INCLINED PLANE

Two important facts may be drawn from the data in Figures 19, 20, and 21. First, it is evident that the data taken in the separately conducted truck and bus impact tests are compatible at least so far as drop tests are concerned. The instruments used in the two series of tests differed radically in theory of operation, yet the results obtained are directly comparable and yield reasonable relations where test conditions are selected which are subject to direct comparison.

The second important fact which may be drawn from Figures 19, 20, and 21 is that the drop impact reactions developed at the pavement surface by the wheels of busses equipped with high pressure pneumatic tires and operated at relatively high speeds are no more severe than those developed by trucks equipped with solid tires at equal or even lower wheel loads and operated at low or very moderate speeds. Further impact tests should be made, however, to determine the reactions produced under a wider range of conditions involving various types and characteristics of vehicle, tire equipment, roughness conditions and particularly

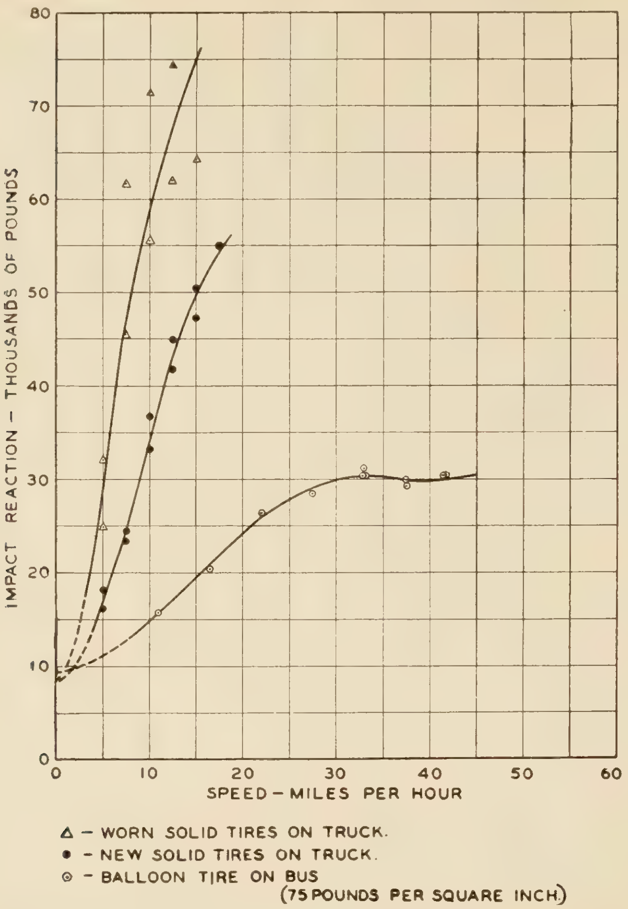

Figure 21.—Comparison of Data from Separately Conducted Truck and Bus Impact Tests, Showing Reactions Produced by Various Types of Tire Equipment. Plotted Points Denote Impact Reactions Produced by Drop After $1\frac{1}{2}$ by 30 Inch Inclined Plane

speed ranges even greater than those covered by the truck and bus tests.

TESTS MADE WITH NATURAL ROAD OBSTRUCTIONS

The artificial obstructions were intentionally made extraordinarily severe in order to expose positively the influences of the factors discussed in the preceding paragraphs. To determine what magnitudes of impact force are developed at and by actual roughness conditions occurring on the highway surface, a number of tests were made at the most severe of such "natural" obstructions as could be readily isolated and existed at locations favorable to the safe conduct of high-speed tests. Only roughness conditions which would retain their shapes and dimensions during tests were used.

In Figure 22, data are given concerning impact forces developed with the bus chassis at three natural surface roughness conditions, for three tire conditions at recommended inflation pressures. The wheel load was 6,000 pounds in each case and the maximum reactions developed under these conditions were approximately two and one-half to three times the static wheel load in the case of the dual high-pressure pneumatics, about two times static for the dual balloon and slightly less for the single balloon equipment. The conclusion which was reached in the discussion concerning artificial obstructions, that drop reactions at moderate speeds are more severe than shock reactions at a given obstruction except at high speeds, is also substantiated by these results.

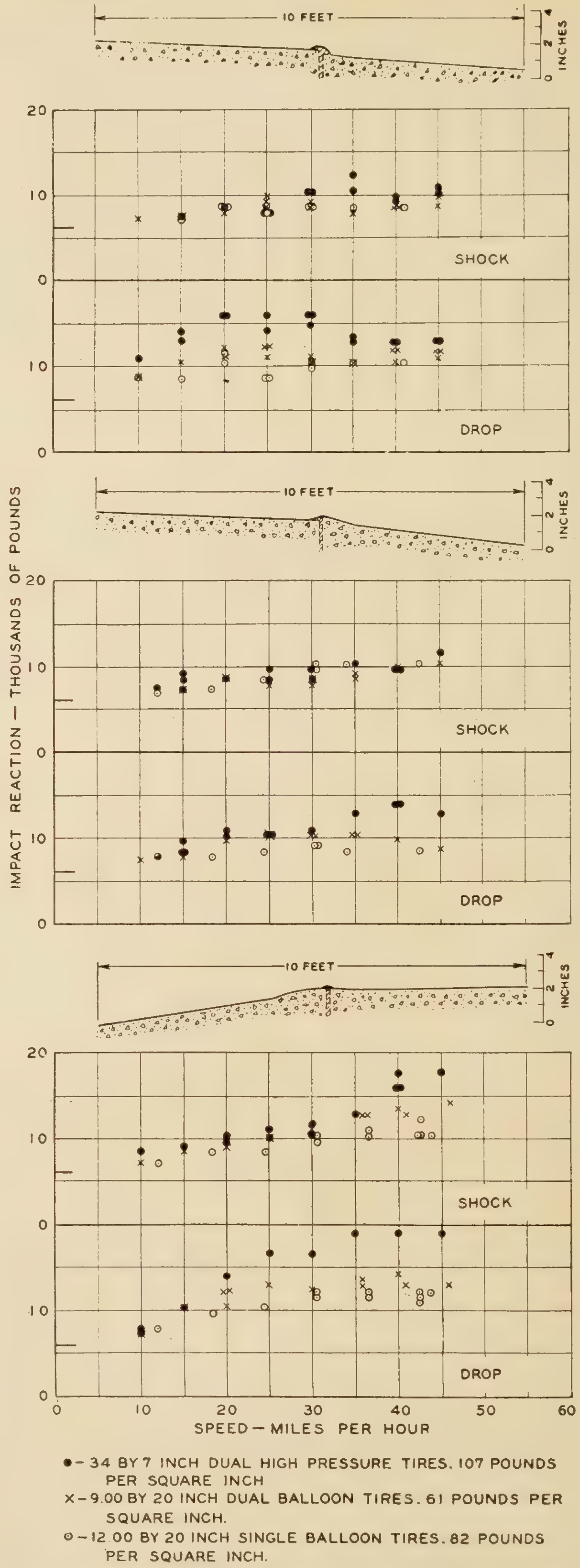

Figure 22.—Impact Reactions Produced by Rear Wheel of Bus Chassis on Encountering Natural Road Roughness Conditions Existing at Transverse Joints on a Concrete Road. Wheel Load, 6,000 Pounds; Direction of Travel, Left to Right

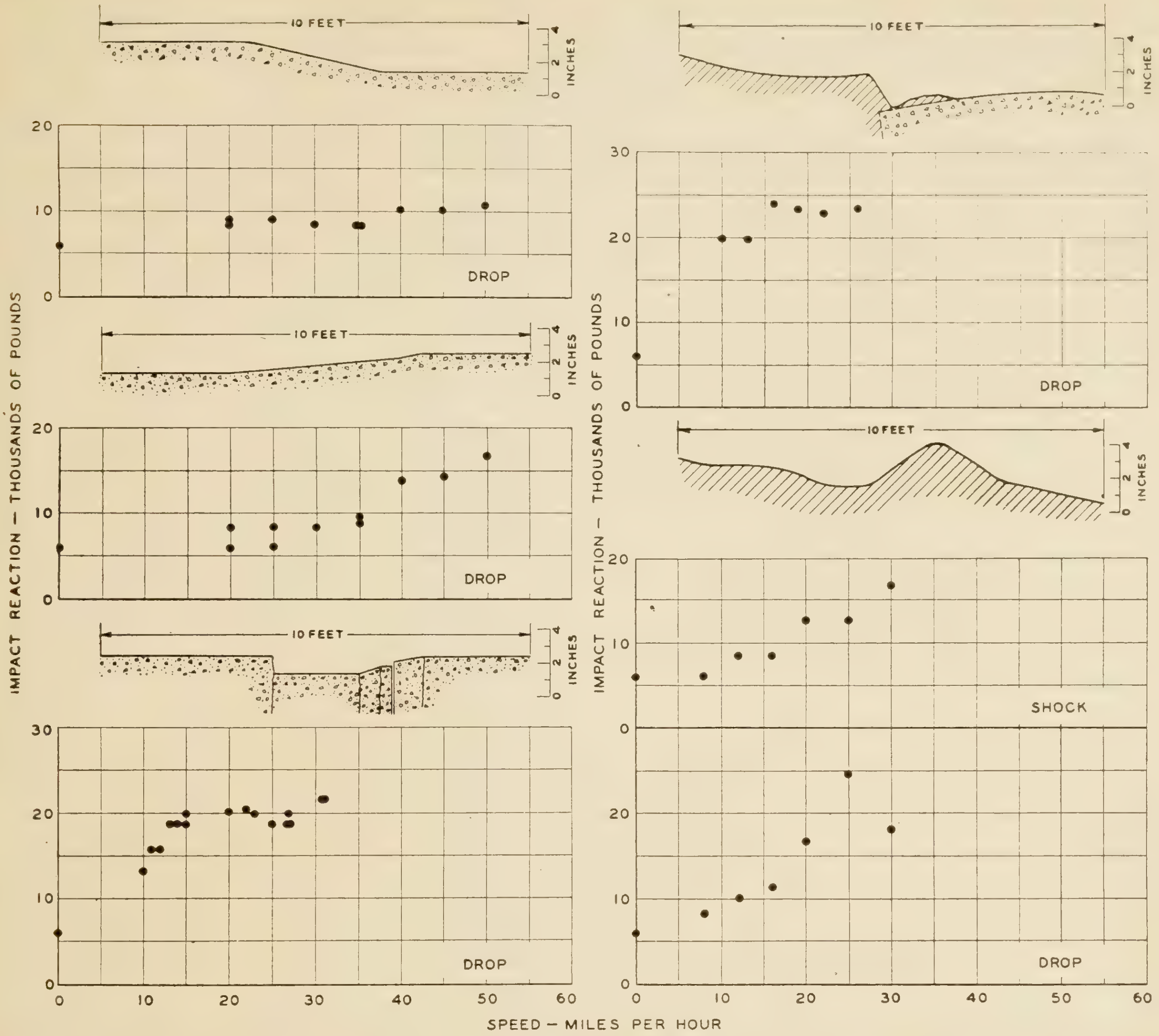

Figure 23.—Impact Reactions Produced by Rear Wheel of Bus Chassis on Encountering Natural Road Roughness Conditions of Various Types. Wheel Load, 6,000 Pounds; Tire Equipment, Dual 34 by 7 Inch High-Pressure; Inflation Pressure 100 Pounds per Square Inch; Direction of Travel, Left to Right

In Figures 23 and 24, additional data concerning actual surface roughness conditions are given for dual 34 by 7 inch high-pressure tires and a wheel load of 6,000 pounds. Although high speeds were not developed for all test conditions because of safety considerations, speeds corresponding to those at which the drop reactions reached maximum values were attained. While in a few instances the reactions measured were from three to four times the static wheel load, it is significant that the surface conditions causing such reactions were all removed by maintenance within one or two weeks after the tests had been made.

It is not believed that actual roughness conditions such as were used in these tests are permitted to remain long in existence on highways even reasonably well maintained. Where they do occur they will probably be found at points where failure has already taken place and repairs are necessary. So far as these tests have indicated, the impact forces developed by balloon and high pressure tires do not reach dangerous proportions as long as the surface is reasonably smooth and designed for the wheel loads involved.

CONCLUSIONS SUMMARIZED

The data on hand were obtained under experimental conditions strictly limited as to tire sizes, tire loads, inflation pressures, rim diameters, rim widths, types of obstruction and vehicle speeds. Subject to these limitations, the following conclusions have been established:

1. Within the economic range of tire inflation pressures (roughly 10 per cent below and above standard), impact reactions vary in almost direct proportion to inflation pressures.

2. For the speeds attained during these tests (up to approximately 55 miles per hour), shock reactions increase approximately in direct proportion to speed.

3. Drop reactions reach maximum values at relatively low speeds and reactions equal to these maximum drop values are not reached under shock conditions except at relatively high operating speeds.

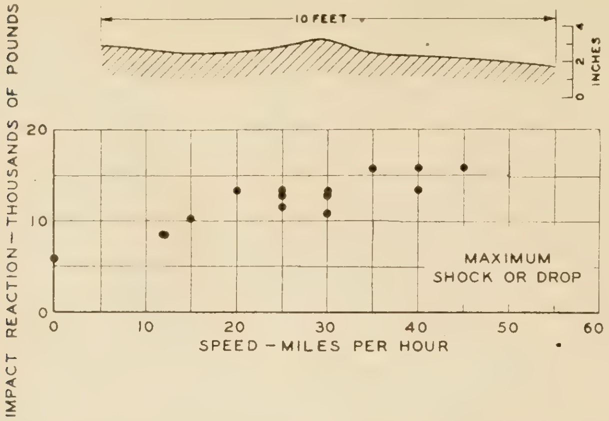

Figure 24.—Impact Reactions Produced by Rear Wheel of Bus Chassis on Encountering Natural Road Roughness Conditions Resulting from Patching Concrete with Bituminous Mixture. Wheel Load, 6,000 Pounds; Tire Equipment, 34 by 7 Inch High-Pressure; Inflation Pressure, 107 Pounds per Square Inch; Direction of Travel, Left to Right

4. For a given natural road roughness condition, the maximum drop reaction which is obtained at a relatively low speed is not exceeded by the shock reactions, except those obtained at relatively high speeds.

5. Severe roughness conditions, such as may be occasionally found existing on actual pavements, may cause reactions as great as three or four times the static wheel load, with high-pressure tire equipment. However, it should be stated that roughness conditions which cause such excessive reactions are extreme and unusual and, in general, the artificial obstructions used in these tests are more severe than natural obstructions commonly occurring on the highway.

6. For a given cross-section of tire, either in the balloon or high-pressure type, variation in rim diameter from 20 to 24 inches has but slight influence on the magnitude of the impact reaction provided the same inflation pressure is used in each case. If standard, recommended inflation pressures are used, then the larger diameter tire causes a lower impact reaction because of the lower inflation pressure which it carries.

7. A change in rim width from 7 to 8 inches causes no appreciable change in the impact reactions of a 9.00 by 20 inch tire, the same inflation pressure being used in each case.

8. At a given inflation pressure, the variation in load from capacity to 50 per cent overload has comparatively little influence on the magnitude of the impact reactions obtained, expressed in force units. Expressed, however, as a percentage of the static load, the values obtained decrease as the load is increased.

9. For a given type, single tires cause lower reactions than dual tires whose combined capacity is equal to that of the single.

THE EFFECT OF THE DIMENSIONS OF TEST SPECIMENS ON THE FLEXURAL STRENGTH OF CONCRETE[1]

Reported by F. V. REAGEL and T. F. WILLIS, Bureau of Materials, Missouri State Highway Department

THE committee on materials of the American Association of State Highway Officials, working through a sectional committee, has been studying the flexure test of concrete in an attempt to standardize the method and apparatus for making this test. After a study of the various devices used, the sectional committee decided that in order to establish a foundation for its work, it would be necessary to design apparatus which would comply as closely as possible with the requirements of the assumptions on which the flexure formula is based. Such a design was adopted at the November, 1929, meeting of the sectional committee. The next step was to choose a standard size of specimen. To do this, it was necessary first to know what effect a variation in the dimensions of the test specimen had on the modulus of rupture, as determined with the new apparatus. The purpose of the experiment reported here was to determine this effect.

As a check on the results and in order to determine what may be expected in the way of uniformity of test results when the specially designed apparatus is used in different laboratories, this complete experiment was performed by each of four State highway laboratories, Illinois, Iowa, Missouri, and Tennessee.

EXPERIMENT COVERED WIDE VARIATION IN TEST SPECIMENS

The experiment consisted of making and testing 768 plain concrete beams. Each laboratory made three series of 64 beams, each series consisting of one beam for every possible combination of the following dimensions:

Width (inches)	4, 6, 8, and 10
Depth (inches)	4, 6, 8, and 10
Length (inches)	20, 26, 32, and 38

Throughout the experiment every effort was made to minimize any effects on the modulus of rupture caused by variables other than those being studied, viz., width and depth of test specimen, and length of span. To this end, every step was carefully outlined prior to performance of the experiment. Materials used by all laboratories were obtained from the same sources; and a man was sent to each laboratory, at the time the first series of beams was made, to assist in promoting uniformity in any way possible. From this viewpoint, it is believed that this is one of the most comprehensive cooperative concrete experiments ever undertaken.

EXPERIMENTAL PROCEDURE OUTLINED

Materials.—A sufficient quantity of each material—cement, sand and coarse aggregate—to supply all four laboratories was obtained from a single source. The cement was a standard brand of Portland cement, the entire amount of which was selected from one bin at the producer's plant, and was thoroughly mixed to insure uniformity before being divided and shipped to the different laboratories. The fine aggregate consisted of a good quality of quartz sand taken from the Missouri River at Boonville, Mo. This material was sacked from stockpile while in a damp condition and one sack out of every four, taken in the order of sacking, was shipped to a different laboratory. The coarse aggregate consisted of crushed Burlington limestone. This material was separated by screening into three sizes, 1 to 3/4 inch, 3/4 to 1/2 inch and 1/2 to 1/4 inch, and a sufficient quantity of each size was shipped to each laboratory. In this way it was assured that all batches of concrete contained an aggregate of prescribed gradation.

Each laboratory remixed its portion of each material and allowed both the fine and the coarse aggregate to become thoroughly air dry prior to the proportioning of batches for concrete.

Proportioning.—All materials were proportioned by weight into batches of the same size. Three laboratories used a batch of 2.5 cubic feet and the other (No. 2) used a 5-cubic-foot batch. All laboratories used the same water-cement ratio, 0.703.

Mixing concrete and molding specimens.—Laboratories Nos. 1, 3, and 4 used 3-cubic-foot capacity mixers and No. 2 used a 7-cubic-foot mixer. The first three washed and drained the mixer after each batch was mixed. Laboratory No. 2, using a 7-cubic-foot mixer, was unable to do this because the concrete discharge chute was so arranged that the mixer drum would not drain readily. The procedure followed in this laboratory in mixing the batches for each series of specimens, was to mix one batch, discard it, and use the next batch as the first in the series. This meant that each batch mixed in Laboratory No. 2 presumably had more mortar in it than any batch mixed in any of the other laboratories.

All specimens were molded according to a prescribed method. For the specimens 4 and 6 inches in depth the forms were filled to overflowing and the sides and ends spaded with a flat spade, by cutting the concrete away from the forms, without tamping or rodding. For the specimens 8 and 10 inches in depth the concrete was placed in the forms in two layers each of which was spaded as described above. As soon as the spading operation was finished, the tops of the specimens were struck off level with the forms by screeding with a wood straight edge, and then floated lightly with a metal trowel.

The average air temperature in the mixing room of all laboratories, and the average temperature of the freshly mixed concrete varied from 67° F. to 76° F.

Curing specimens.—All laboratories cured the beams for the first 24 hours with wet burlap and the following 27 days in moist room. The temperature and humidity records of the moist rooms during the curing period, submitted by all laboratories, showed that curing conditions were very uniform. The average curing temperatures for all laboratories fell in the range, 70° F. ±4° F.; the maximum range for any one laboratory was from 62° F. to 77° F. and these extremes occurred only for parts of a few days. The average humidities for all laboratories fell in the range, 98.5 per cent ± 1.5

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[1] This article is a report of an experiment conducted by the sectional committee on flexure tests of concrete, of the American Association of State Highway Officials. The Sectional Committee is composed of the following members: F. V. Reagel, engineer of materials, Missouri State Highway Department, chairman; A. V. Bratt, engineer of materials, Massachusetts State Highway Department; E. W. Bauman, engineer of materials, Tennessee State Highway Department; V. L. Glover, engineer of materials, Illinois State Highway Department; F. G. Lang, engineer of materials, Minnesota State Highway Department; H. S. Mattimore, engineer of materials, Pennsylvania State Highway Department; Bert Myers, engineer of materials, Iowa State Highway Department; The U. S. Bureau of Public Roads. The report was submitted to and approved by the committee on materials of the American Association of State Highway Officials.

per cent; the maximum range for any one laboratory was from 97 per cent to 100 per cent.

Testing specimens.—All specimens were tested in a saturated condition at the age of 28 days. They were tested in the A. A. S. H. O. specially designed thirdpoint apparatus mounted on a universal testing machine. The speed of cross head varied from 0.05 to 0.1 inch per minute. Beams were placed in the machine so that the top faces as molded were in tension during test.

The cross-section of the beam was measured at the plane of fracture, the width to an accuracy of 0.1 inch, and the depth to an accuracy of 0.05 inch. The modulus of rupture was calculated from the formula,

$$f=\frac{S(L+3/4\ W)}{bd^2}$$

Where

f = Modulus of rupture in pounds per square inch.
L = Total applied load in pounds.
S = Span of beam in inches.
W = Weight of beam in pounds.
b = Width of beam in inches.
d = Depth of beam in inches.

Description of apparatus.[2]—Figures 1 and 2 show different views of the apparatus used in making these tests. The test specimen is supported by the lower cross members of two free-swinging stirrups. These stirrups in turn are swung from knife-edge supports on a heavy steel member fastened across the top of the cage of the testing machine. This method of supporting the specimen eliminates any possibility of restraint of the elongation of the fibers on the tension side of the test specimen during a test.

The cross member on the lower end of one stirrup is fitted with a cylindrical segment which can rotate in a socket in a plane perpendicular to the axis of the beam and above this a knife-edge support permitting rotation in a plane parallel with the axis of the beam. The other cross member has only the knife-edge bearing. These accessories insure uniform support to a specimen during test even though the specimen is not a perfect rectangular prism.

The load-applying mechanism consists essentially of a secondary beam parallel to the axis of the specimen with a transverse plate at each end of the beam. The load is applied by the moving cross head of the machine through a cylindrical segment and socket to the center of the secondary beam and then transferred through cylindrical segments (at right angles to the first) at each end of the secondary beam and transverse plates and 2-inch rollers to the test specimen. The rollers and plates are set so that the load is applied at the one-third points of the span of the test specimen. The use of these various accessories eliminate the possibility of inducing torsional stress in the specimen, a condition often found where a rigid load-applying apparatus is used. The various parts of the load-applying mechanism are joined by flexible springs which permit the entire mechanism to be handled as a unit when placing a specimen in position.

It is believed that this apparatus successfully performs its intended function, viz., to insure that the specimen is subjected only to coplanar forces perpendicular to the axis of the beam and that there is no restraint to the deformation of the fibers of the specimen.

In the tests under discussion the apparatus appeared to work perfectly. All the devices which were installed to insure proper stressing of the specimen functioned as intended. While the apparatus was a little cumbersome and each test required considerable time, this was largely because the machine had to be built to accommodate the various sizes of beams used in this experiment. An apparatus similarly constructed but intended for use on a single size of specimen would be much simpler to operate.

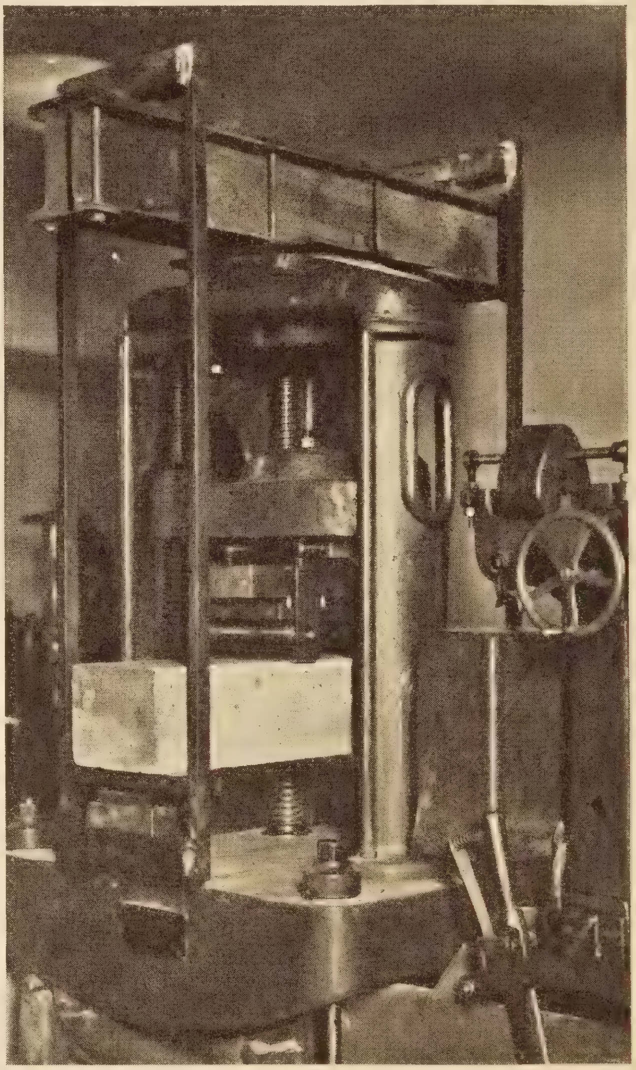

Figure 1.—General View of Apparatus for Flexure Tests of Concrete Beams, Showing Specimen in Place, Ready to be Tested

UNIFORMITY OF MATERIALS AND CONCRETE TESTED

The tests performed by the four laboratories on the materials used in this experiment are shown in Tables 1, 2, and 3. In general the data are very consistent and show that the attempt to provide similar materials for all the laboratories was successful.

The tabulation given below shows the consistency of the concrete used by the different laboratories.

Laboratory No.	1	2	3	4
Average slump (inches)	1. 7	1. 1	2. 4	0. 8
Maximum slump (inches)	2. 2	1. 8	2. 7	0. 9
Minimum slump (inches)	1. 5	0. 9	2. 1	0. 5

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[2] This apparatus was designed for the committee by F. N. Wray, research assistant, Missouri State Highway Department, and embodies several suggestions made by Messrs. Bert Myers and A. E. Stoddard of the Iowa State Highway Department and T. F. Willis of the Missouri State Highway Department.

TABLE 1.—*Characteristics of cement used in flexure tests of concrete beams*

Laboratory No.	Sample No.	Tensile strength (pounds per square inch)		Per cent water at normal consistency	Time of set (minutes)		Fineness: Per cent retained on No. 200 screen	Soundness
		7 days	28 days		Initial	Final		
1	1	395	461	23. 6	190	370	6. 8	Satisfactory.
	2	397	478	23. 6	160	355	6. 1	Do.
	3	361	423	23. 6	180	370	6. 3	Do.
Average		384	454	23. 6	177	365	6. 4	Do.
2	1	388	478	24. 0	185	270	5. 8	Do.
	2	377	452	24. 0	185	260	5. 9	Do.
	3	378	428	24. 5	205	335	6. 0	Do.
Average		381	452	24. 2	192	288	5. 9	Do.
3	1	367	520	23. 5	180	360	7. 5	Do.
	2	412	492	24. 0	205	385	6. 7	Do.
	3	408	447	24. 0	210	405	6. 1	Do.
Average		396	486	23. 8	198	383	6. 8	Do.
4	1	417	485	23. 0	227	410	5. 4	Do.
	2	425	473	23. 0	230	400	6. 0	Do.
	3	405	465	23. 0	234	403	6. 0	Do.
Average		416	474	23. 0	230	404	5. 8	Do.
Average of all laboratories		394	466	23. 6	204	360	6. 2	Do.

TABLE 2.—*Characteristics of fine aggregate used in flexure tests of concrete beams*

Laboratory No.	Sample No.	Weight per cubic foot (dry-rodded)	Per cent void space	Mechanical analysis, per cent passing square mesh screens						Strength ratio [1]	
				No. 4	No. 8	No. 14	No. 28	No. 48	No. 100	7 days	28 days
1	[2] 1	114	31	97. 2	88. 6	69. 7	34. 4	11. 6	2. 9	1. 22	1. 08
	2	114	31	97. 0	85. 1	64. 5	30. 3	10. 8	1. 0	1. 23	1. 07
Average		114	31	97. 2	88. 0	68. 8	33. 4	11. 5	2. 4	1. 22	1. 08
2	1	115	30	95. 5	84. 6	65. 5	33. 7	10. 0	1. 8	1. 09	1. 12
	2	115	30	96. 0	87. 0	70. 0	37. 0	12. 0	2. 0	1. 30	1. 18
	3	115	30	96. 0	88. 0	70. 0	39. 0	12. 0	2. 0	1. 14	1. 14
Average		115	30	95. 8	86. 5	68. 5	36. 6	11. 3	1. 9	1. 18	1. 15
3	1	114	31	96	84	62	29	9	1	1. 31	. 95
	2	113	32	98	86	66	30	9	1	1. 15	1. 07
	3	114	31	95	83	60	26	8	1	1. 10	1. 17
Average		114	31	96. 3	84. 3	62. 7	28. 3	8. 7	1. 0	1. 19	1. 06
4	1	[3] 102	[3] 38	97. 3	89. 4	70. 2	31. 9	11. 5	1. 8	1. 23	1. 16
	2	[3] 102	[3] 39	96. 3	86. 6	65. 4	30. 5	9. 7	1. 1	1. 26	1. 17
	3	[3] 102	[3] 39	96. 7	86. 3	66. 4	30. 2	10. 8	1. 7	1. 39	1. 21
Average		[3] 102	[3] 39	96. 8	87. 4	67. 3	30. 9	10. 7	1. 5	1. 29	1. 18
Average of all laboratories		114	31	96. 5	86. 5	66. 8	32. 3	10. 7	1. 7	1. 22	1. 12

[1] In terms of values given by standard Ottawa sand.

[2] Average of test results on 5 samples.

[3] Values determined for damp loose volumes—excluded from average.

NOTE.—Specific gravity varied from 2.63 to 2.65 but average from each laboratory gave 2.64.

MEASUREMENTS OF MODULUS OF RUPTURE SHOW SIMILAR UNIFORMITY

In table 4 are given the means of the variations of the individual tests of the three series from the average of the three series of tests conducted in each of the four laboratories. The values in the table are expressed as percentages of the average moduli of rupture for the four series. The table is not complete in that it does not give values for all the different sizes of beams, but the values given are representative of the entire group. For each size of beam the average of the mean variations for the four laboratories is tabulated; and for each laboratory the average of the mean variations for all sizes is also given.

TABLE 3.—*Characteristics of coarse aggregate used in flexure tests of concrete beams*

Laboratory No.	Sample No.	Weight per cubic foot (dry-rodded)	Per cent void space	Apparent specific gravity	Per cent absorption in 30 minutes	Per cent passing 1½-inch square screen	Per cent passing ¾-inch square screen	Per cent passing ⅜-inch square screen
1	[1] 1	91. 8	45. 2	2. 68	0. 2	100	76. 2	13. 4
2	1	95. 1	43. 3	2. 69	0. 4	100	72. 0	14. 0
	2	96. 0	43. 0	2. 69	0. 3	100	73. 2	15. 3
	3	95. 6	43. 1	2. 69	0. 3	100	76. 5	13. 5
Average		95. 6	43. 1	2. 69	0. 3	100	73. 9	14. 3
3	1	92. 7	44. 1	2. 66	0. 5	100	76. 0	15. 0
	2	90. 4	45. 7	2. 67	0. 4	100	77. 0	15. 0
	3	90. 0	46. 1	2. 67	0. 4	100	77. 0	14. 0
Average		91. 0	45. 3	2. 67	0. 4	100	76. 7	14. 7
4	1	92. 0	45. 7	2. 71	0. 2	100	70. 0	9. 2
	2	92. 0	45. 5	2. 70	0. 1	100	70. 9	8. 0
	3	91. 0	46. 3	2. 71	0. 1	100	63. 6	8. 5
Average		91. 7	45. 8	2. 71	0. 1	100	68. 2	8. 6
Average of all laboratories		92. 5	44. 9	2. 69	0. 25	100	73. 8	12. 8

[1] Average of test results on 4 samples.

It will be observed that, in general, the larger sizes of beams showed a lower mean variation. This may be due to the effect of coarse aggregate, which in this experiment was of 1-inch maximum size. The difference in mean variation of results for the large and small beams is not entirely consistent, nor is its magnitude sufficient to warrant the conclusion that the smaller sizes of beams should not be used with 1-inch coarse aggregate. There is, however, an indication that the larger sizes given more consistent results.

The averages of the mean deviations for each laboratory range from 3.16 per cent to 4.40 per cent with a grand average of 3.86 per cent. This is considered better than ordinary for concrete testing.

Table 5 shows the percentage variation of the average of each laboratory's results from the average of the four laboratories for several sizes of specimen; and appended to the table are average moduli of rupture for all tests performed by each laboratory.

In either the values for any one laboratory or the averages for the four laboratories there is no consistent relation between percentage variation and size

TABLE 4.—*Mean percentage variations of individual test results of three series from the average values of modulus of rupture for all series*

Dimensions of beam [1]	Mean variation of individual test result				Average of all laboratories
	Laboratory No. 1	Laboratory No. 2	Laboratory No. 3	Laboratory No. 4	
Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
4 by 4 by 18	4. 07	7. 31	3. 92	6. 24	5. 38
4 by 4 by 24	1. 75	7. 64	5. 58	3. 62	4. 65
4 by 4 by 30	3. 10	5. 42	7. 90	3. 36	4. 94
4 by 4 by 36	3. 53	6. 43	5. 50	5. 49	5. 24
6 by 6 by 18	0. 71	3. 26	4. 13	4. 96	3. 27
6 by 6 by 24	3. 18	6. 44	2. 17	4. 98	4. 19
6 by 6 by 30	2. 30	3. 22	2. 17	1. 45	2. 28
6 by 6 by 36	4. 43	3. 49	5. 32	5. 07	4. 58
8 by 8 by 18	2. 01	3. 23	4. 03	5. 97	3. 81
8 by 8 by 24	4. 04	4. 64	3. 58	0. 76	3. 26
8 by 8 by 30	4. 56	4. 00	1. 97	2. 86	3. 35
8 by 8 by 36	2. 61	3. 99	3. 07	7. 14	4. 20
10 by 10 by 18	2. 31	3. 71	1. 34	2. 57	2. 48
10 by 10 by 24	2. 64	2. 76	4. 32	2. 92	3. 16
10 by 10 by 30	5. 84	1. 95	1. 35	4. 14	3. 32
10 by 10 by 36	3. 43	2. 92	3. 69	4. 40	3. 61
Average of all sizes	3. 16	4. 40	3. 75	4. 12	3. 86

[1] Dimensions are given in depth, width and length of span. For total length of beam, add 2 inches.

of beam. This indicates that the beam size did not affect the uniformity of results obtained by the different laboratories; in other words the different laboratories check each other as well with one size of beam as with another.

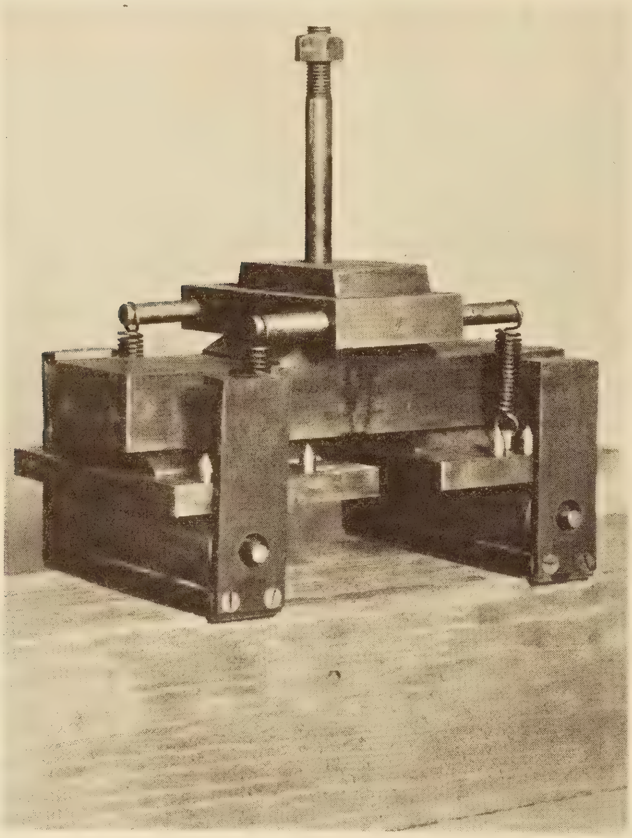

Figure 2.—Apparatus for Third-Point Application of Load to Concrete Beams

Table 5.—*Percentage variation of average values of modulus of rupture for each laboratory from average of four laboratories*

Dimensions of beam	Variation of average modulus of rupture				Average of all laboratories
	Laboratory No. 1	Laboratory No. 2	Laboratory No. 3	Laboratory No. 4	
Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
4 by 4 by 18	0.46	12.24	11.44	1.49	6.41
6 by 4 by 18	.22	5.23	7.09	2.21	3.68
8 by 4 by 18	1.26	5.51	1.49	2.41	2.67
10 by 4 by 18	4.25	4.14	1.73	1.84	2.99
4 by 6 by 24	3.09	5.44	4.20	1.73	3.62
6 by 6 by 24	5.65	5.77	2.04	2.28	3.94
8 by 6 by 24	1.91	9.42	1.19	6.32	4.71
10 by 6 by 24	5.80	8.88	.11	3.20	4.50
4 by 8 by 30	2.60	5.20	.65	2.21	2.67
6 by 8 by 30	.49	3.62	4.00	1.00	2.28
8 by 8 by 30	9.34	7.67	1.92	.26	4.80
10 by 8 by 30	4.41	7.30	3.27	5.16	5.04
4 by 10 by 36	.63	4.65	1.37	4.10	2.70
6 by 10 by 36	5.28	2.51	5.81	2.90	4.12
8 by 10 by 36	6.06	7.51	4.34	5.66	5.89
10 by 10 by 36	5.82	6.34	6.34	6.72	6.30
Average of all sizes	3.58	6.34	3.56	3.09	4.14
Average modulus of rupture for all tests	787	857	800	804	812

The average percentage variations are shown in the next to the last horizontal line. The average variations for the results from three of the laboratories are approximately the same, but that of laboratory No. 2 is nearly twice as great. The average of all results for laboratory No. 2 is considerably above the averages for the other laboratories, and this is consistently true of their individual results. In other words the results were consistent within themselves, but for some reason were higher than the corresponding results of the other laboratories. The record of molding, curing, and testing specimens reveals only one radical difference between the procedure used by this laboratory and that used by the others, viz., that they mixed a double batch, did not wash or drain the mixer after mixing each batch, and therefore probably had a higher mortar content in each batch than did the other laboratories. Only experiment can tell whether this was the cause of the higher test results.

In spite of this the grand average for all laboratories is only 4.14 per cent, which is approximately the same as the four laboratories' average mean percentage variation of individual tests from the average of three series. In other words, it appears that the degree of uniformity between the average results obtained in four different laboratories was as good as the uniformity between the three series of tests run in any one laboratory. This indicates that by maintaining properly standardized

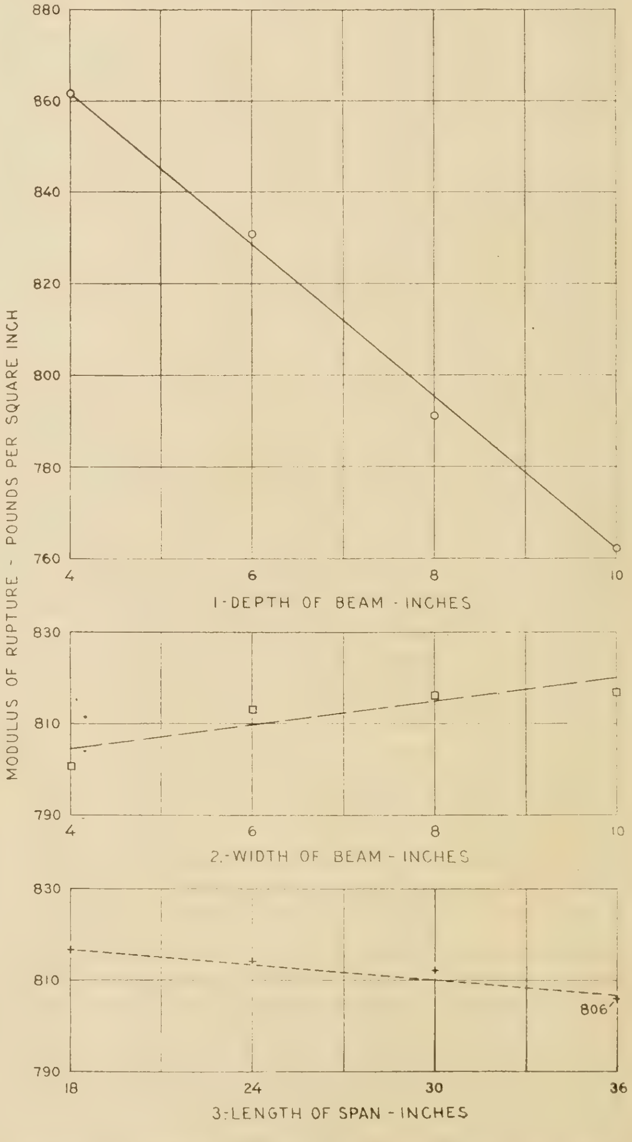

Figure 3.—Effect of Depth of Beam, Width of Beam, and Length of Span on Modulus of Rupture of Concrete Test Specimens, as Shown by Averages of Results from Four Laboratories

procedures and using the same materials, different laboratories can check each other within reasonable limits. The results are particularly gratifying in view of the time and expense gone to in preparing for this experiment.

DATA ANALYZED AND DISCUSSED

The results of the tests of modulus of rupture are given in Table 6 and Figures 3 to 9. Table 6 contains values of modulus of rupture for all the tests. The tabulated values which are not marked as averages are themselves averages of three tests made on different days. It will be observed that a complete system of averaging has been carried out. The different types of average which are given may be described as follows:

For a given laboratory, a given span, and a given width:
  The average value given by all four depths.
For a given laboratory, a given span, and a given depth:
  The average value given by all four widths.
For a given laboratory and a given span:
  The average value given by all combinations of width and depth.
For all four laboratories and a given span:
  The average value given by each combination of width and depth.
For all four laboratories, a given span, and a given width:
  The average value given by all four depths.
For all four laboratories, a given span, and a given depth:
  The average value given by all four widths.
For all four laboratories and a given span:
  The average value given by all combinations of width and depth.
For a given laboratory, all four spans, and a given width:
  The average value given by all four depths.
For a given laboratory, all four spans, and a given depth:
  The average value given by all four widths.
For a given laboratory and all four spans:
  The average value given by all combinations of width and depth.[3]
For all four laboratories, all four spans, and a given width:
  The average value given by all four depths.

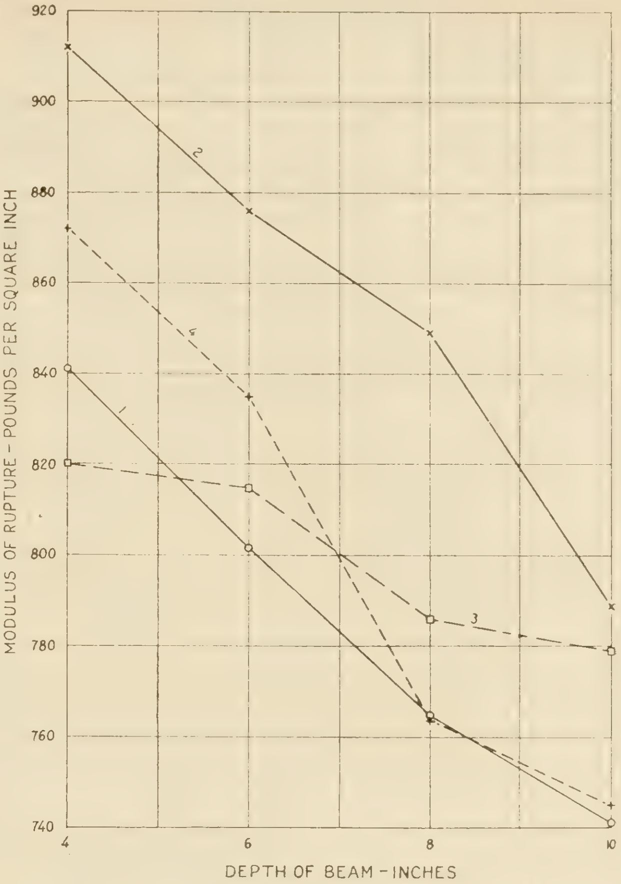

FIGURE 4.—EFFECT OF DEPTH OF BEAM ON THE MODULUS OF RUPTURE OF CONCRETE TEST SPECIMENS. AVERAGE VALUES FOR ALL WIDTHS OF BEAM AND ALL LENGTHS OF SPAN ARE PLOTTED SEPARATELY FOR EACH LABORATORY

TABLE 6.—*Results of tests to determine the effect of the dimensions of test specimen on the flexural strength of concrete. Values of the modulus of rupture, in pounds per square inch, are tabulated according to width and depth of beam and length of span*

Laboratory No.	Width of beam	18-inch span					24-inch span					30-inch span					36-inch span					Average of all spans and all depths	Depth of beam	Average of all spans and all widths
		Depth of beam in inches				Average	Depth of beam in inches				Average	Depth of beam in inches				Average	Depth of beam in inches				Average			
		4	6	8	10		4	6	8	10		4	6	8	10		4	6	8	10				
	Inches																						*Inches*	
1	4	878	777	754	701	778	876	784	752	752	791	828	806	749	772	789	831	799	797	736	791	787	4	841
	6	859	842	817	734	813	850	785	755	729	780	811	769	797	771	787	825	790	760	718	773	788	6	802
	8	860	825	731	743	790	813	823	768	721	781	831	823	709	766	782	844	803	766	713	782	784	8	765
	10	833	824	791	793	810	858	796	751	731	784	850	792	759	748	787	799	786	775	728	772	788	10	741
Average		858	817	773	743	798	850	797	757	733	784	830	798	754	764	786	825	795	775	724	780	787		787
2	4	981	845	843	786	864	899	853	799	777	832	941	848	809	719	829	856	857	814	765	824	837	4	912
	6	906	849	909	787	863	918	880	844	800	860	918	817	830	785	838	963	867	860	777	867	857	6	876
	8	919	902	857	775	863	890	918	890	834	884	927	900	842	803	868	913	888	860	816	869	871	8	849
	10	906	890	865	774	859	904	920	867	798	872	868	883	852	807	852	888	895	862	822	867	864	10	789
Average		928	871	868	780	862	903	893	850	802	862	913	862	833	778	847	905	877	849	795	857	857		857
3	4	774	750	771	761	764	819	775	758	791	786	810	816	764	742	783	777	781	766	721	761	773	4	820
	6	800	799	769	750	779	801	815	764	778	789	812	817	869	786	795	795	833	810	802	811	793	6	815
	8	858	829	802	813	825	861	829	746	810	812	837	850	797	795	820	842	850	792	792	819	817	8	786
	10	855	804	867	770	824	849	844	783	770	812	822	825	820	765	808	811	838	794	822	816	815	10	779
Average		822	794	802	773	798	832	816	762	787	799	820	826	787	772	801	806	825	791	784	802	800		800
4	4	861	872	784	713	807	893	823	797	751	816	892	880	752	767	823	879	779	725	701	771	804	4	872
	6	880	928	794	759	840	892	850	774	784	825	863	792	809	761	806	895	808	727	736	792	816	6	835
	8	850	829	701	745	781	855	786	747	735	781	855	864	780	762	815	870	813	780	716	795	793	8	764
	10	886	854	755	737	808	887	818	774	763	810	852	852	753	766	805	837	808	766	721	783	802	10	745
Average		869	871	759	738	809	882	819	773	758	808	866	847	773	764	812	870	802	749	719	785	804		804
Average of four laboratories	4	874	811	788	741	803	872	809	777	768	807	868	837	769	750	806	836	804	776	731	787	801	4	862
	6	861	854	822	757	823	865	832	784	773	814	851	798	801	776	806	870	824	790	758	810	813	6	832
	8	871	846	773	769	815	855	839	788	775	814	863	859	782	781	821	868	838	799	759	816	816	8	791
	10	870	843	819	769	825	875	845	794	765	820	848	838	794	771	813	834	832	799	773	810	817	10	763
Average		869	838	801	759	817	867	831	786	771	814	857	833	787	769	812	852	824	791	755	806	812		812

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[3] This average value appears twice in Table 6.

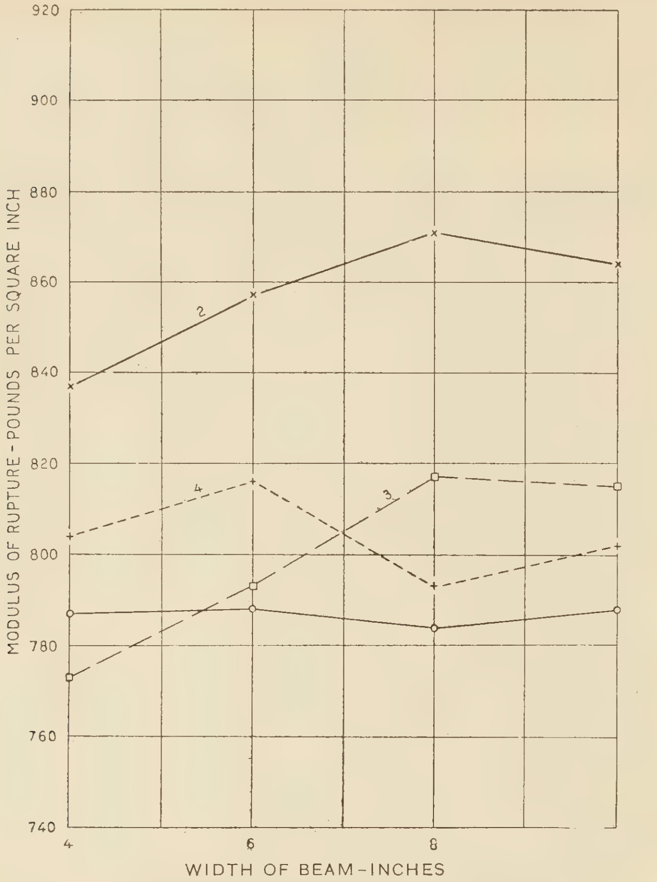

FIGURE 5.—EFFECT OF WIDTH OF BEAM ON THE MODULUS OF RUPTURE OF CONCRETE TEST SPECIMENS. AVERAGE VALUES FOR ALL DEPTHS OF BEAM AND ALL LENGTHS OF SPAN ARE PLOTTED SEPARATELY FOR EACH LABORATORY

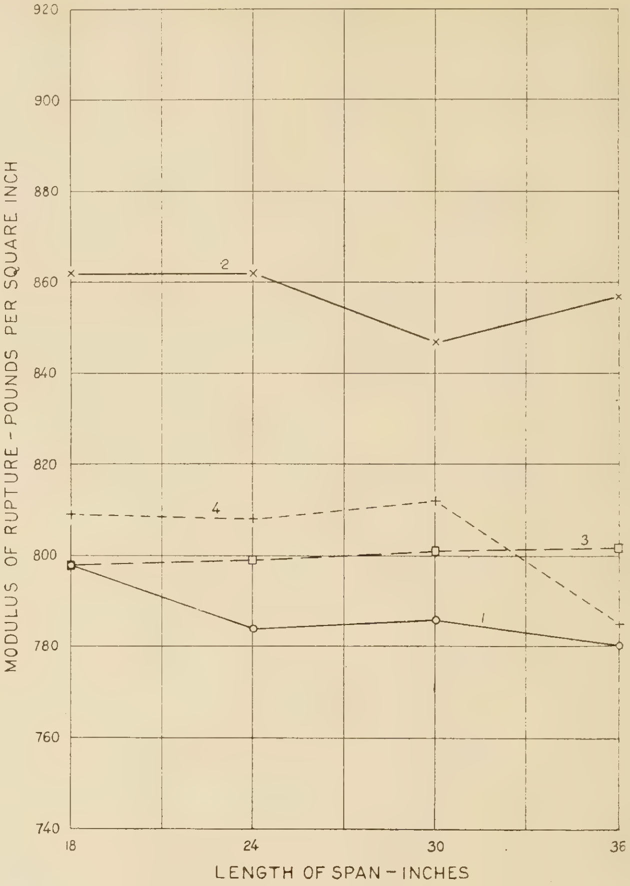

FIGURE 6.—EFFECT OF LENGTH OF SPAN ON THE MODULUS OF RUPTURE OF CONCRETE TEST SPECIMENS. AVERAGE VALUES FOR ALL DEPTHS AND WIDTHS OF BEAM ARE PLOTTED SEPARATELY FOR EACH LABORATORY

For all four laboratories, all four spans, and a given depth:
The average value given by all four widths.
The grand average value of all test results, i. e., all four laboratories, and all combinations of span length, width of beam and depth of beam.[4]

In Figure 3 are given the final average curves showing the variation of modulus of rupture with depth of beam, width of beam and length of span. In the case of depth each plotted point represents the average of all test results from the four laboratories and all combinations of width of beam and length of span. Similar averages are represented by the plotted points on the other two graphs. In Figures 4, 5, and 6, the average results are plotted separately for each laboratory. For example, in Figure 4 each curve represents an average of all the data from a given laboratory, and each plotted point represents the average modulus of rupture given by all tests, in a given laboratory, of beams of a given depth, regardless of width of beam and length of span. The curves of Figures 4, 5, and 6 bring out clearly the fact, previously noted, that the test results obtained in Laboratory No. 2 were consistently higher than those obtained in the other three laboratories.

In Figures 7, 8, and 9 data from the four laboratories are averaged, different values of the three dimensions, width, depth, and length of span, being represented by separate curves and panels. Thus, in Figure 7 each panel contains data relative to a given length of span, averaged for the four laboratories; and each curve shows average results of tests of beams of a given width. Each plotted point, therefore, represents the average modulus of rupture for the tests, in all four laboratories, of all beams having a given depth, a given width, and a given length of span. Average curves are drawn to illustrate the trend of the variation for all widths. Figures 8 and 9 are constructed in a similar manner to show the effect of width of beam and length of span.

MODULUS VARIES INVERSELY WITH DEPTH OF SPECIMEN

Curve No. 1 in Figure 3, which is based on the averages of all the results from all the laboratories, shows that there is practically a straight line relationship between depth of specimen and modulus of rupture, the modulus of rupture decreasing 1.9 per cent for each inch increase in the depth of specimen.[5] Increasing the depth of specimen from 4 to 10 inches resulted in decreasing the average modulus of rupture from 862 to 763 pounds per square inch, a net reduction of 100 pounds per square inch for a 6-inch increase in depth of specimen.

The curves of Figure 4 show that the results of each of the four laboratories, considered individually, have the same qualitative relationship; while the curves of Figure 7 indicate that the relationship is approximately the same regardless of width of specimen or length of span.

EFFECT OF WIDTH NEGLIGIBLE

Figures 3, 5, and 8 show the effect of width of test specimen on the modulus of rupture. Curve No. 2 is Figure 3, based on the averages of results of all tests, shows that the modulus of rupture increased very slightly

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[4] This arrangement value appears twice in Table 6.

[5] This confirms qualitatively the results of tests by the Portland Cement Assotion. See Report of Director of Research, November, 1928, p. 174.

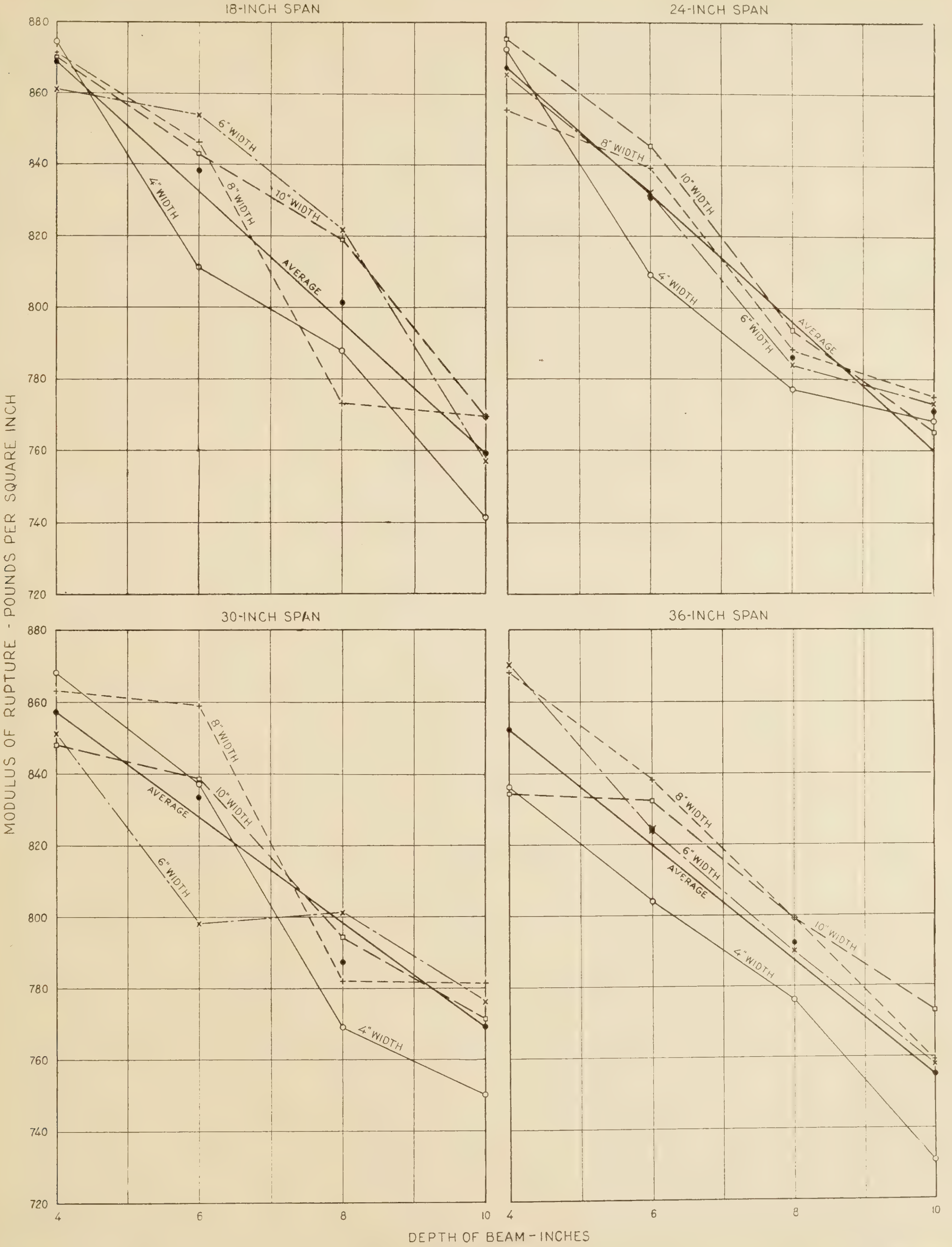

Figure 7.—Effect of Depth of Beam on the Modulus of Rupture of Concrete Test Specimens. Values of Modulus of Rupture are Averaged for All Four Laboratories, But are Plotted Separately for Each Width of Beam and Each Length of Span

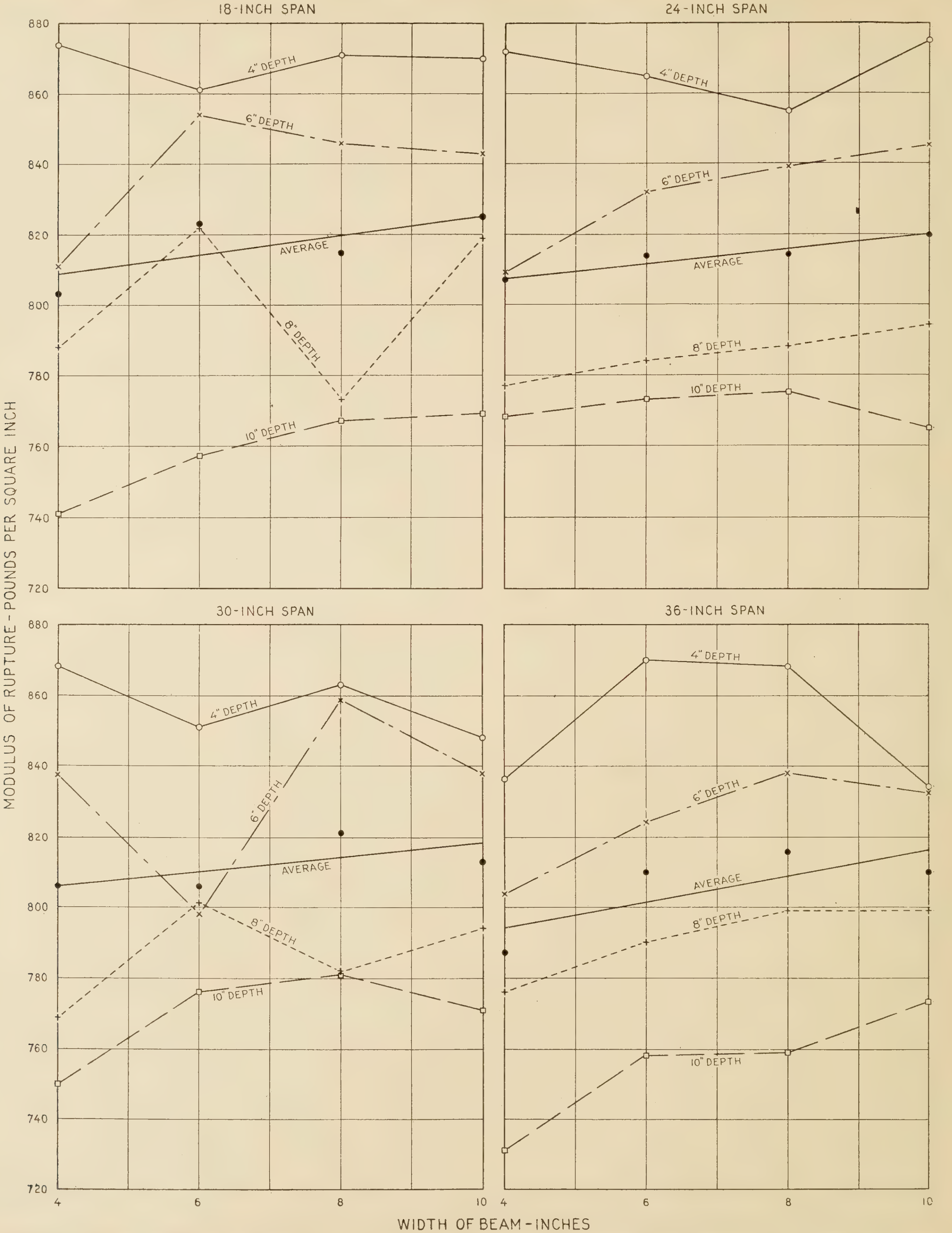

Figure 8.—Effect of Width of Beam on the Modulus of Rupture of Concrete Test Specimens. Values of Modulus of Rupture are Averaged for All Four Laboratories, But are Plotted Separately for Each Depth of Beam and Each Length of Span

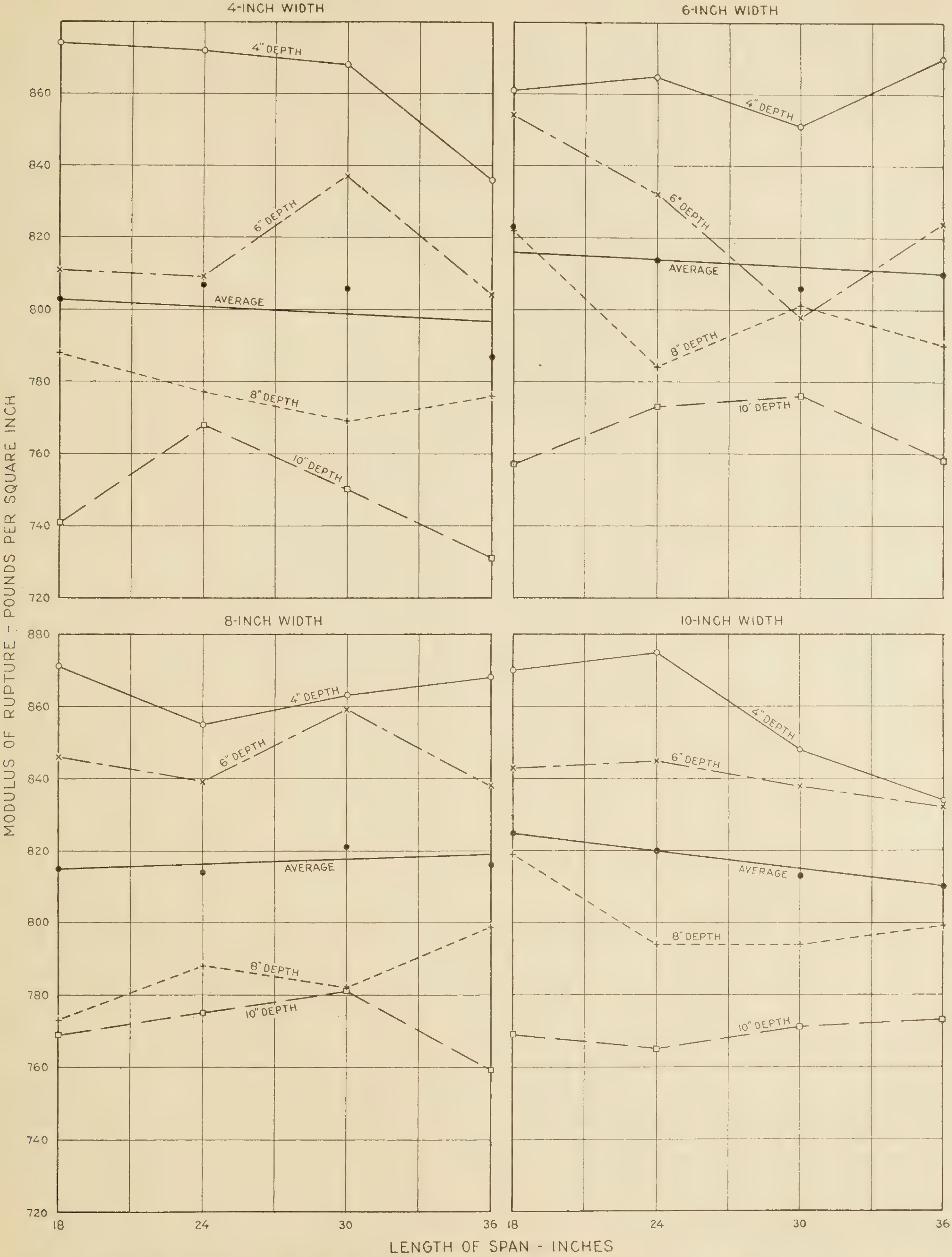

FIGURE 9.—EFFECT OF LENGTH OF SPAN ON THE MODULUS OF RUPTURE OF CONCRETE TEST SPECIMENS. VALUES OF MODULUS OF RUPTURE ARE AVERAGED FOR ALL FOUR LABORATORIES, BUT ARE PLOTTED SEPARATELY FOR EACH WIDTH AND EACH DEPTH OF BEAM

as the width of specimen increased. The average modulus of rupture increased approximately 16 pounds per square inch when the width of beam was increased from 4 to 10 inches. The greatest increase is between the 4 and 6 inch widths. It is possible that the results for the 4-inch width are slightly low on account of the difficulty of molding specimens of this width properly.

It may be noted that this increase of 16 pounds per square inch is but 2 per cent of the average value of modulus of rupture, 801, for beams of 4-inch width. An examination of Table 4 will show that the mean percentage variation of individual test results from the average of the three series is generally much greater than 2 per cent. There are individual cases where it is less than 1 per cent, but the average for each laboratory is greater than 3 per cent, and the average for all tests is 3.86 per cent. Similarly, in Table 5, it is shown that the variation of the average for one laboratory varies from the average of four laboratories by values running up to 9.42 per cent, with an average for all tests of 4.14. These facts make it apparent that the indicated variation in modulus of rupture due to changes in the width of beam is less than the probable variation due to influences not in the control of the experimenter.

Reference to Figure 5 shows that the trend of the curve in Figure 3 is due to the results of laboratories Nos. 2 and 3, and that average curves for the other two laboratories would approximate horizontal lines. It is, therefore, doubtful that increasing the width of specimen causes an increase in the modulus of rupture. For all practical purposes the average results of all four laboratories indicate that varying the width of the specimen had no effect on the modulus of rupture.

NO MARKED EFFECT DUE TO VARIATION IN SPAN LENGTH

Figures 3, 6, and 9 show the effect of the length of span. Curve No. 3 in Figure 3, based on the averages of results of all tests, shows that the modulus of rupture decreased very slightly as the span length was increased. The average modulus of rupture decreased approximately 9 pounds per square inch when the length of span was increased from 18 inches to 36 inches. Figure 6 shows the average results for each laboratory. It will be noted that two of the laboratories (Nos. 2 and 3) show practically no effect from varying span, one of them (No. 1) showed a decrease of 18 pounds per square inch, and one of them (No. 4) showed a decrease of 25 pounds per square inch. These decreases are very small, are well within the limit of error of the averages, and are not corroborated by all the laboratories. This would indicate that the length of span had no appreciable effect on the modulus of rupture.[6]

CONCLUSIONS SUMMARIZED

The following conclusions, derived from the results of this experiment, are naturally restricted in their application to apparatus in which the specimen is loaded at the third points.

1. Variation in depth of specimen causes sufficient variation in the modulus of rupture that it is necessary to standardize this dimension.
2. Variation in width of specimen has a negligible effect on the modulus of rupture. This dimension might have more influence if other sizes of coarse aggregate were used.
3. Variation in the length of span has a negligible effect on the modulus of rupture.
4. Different laboratories using similar materials and methods of test can check each other with a variation not exceeding 5 per cent.

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[6] This confirms, qualitatively, the results of tests by the Portland Cement Association. See Report of Director of Research, November, 1928, p. 174.

MEETING OF THE JOINT COMMITTEE ON CONCRETE AND REINFORCED CONCRETE

THE Joint Committee on Standard Specifications for Concrete and Reinforced Concrete met in the rooms of the Western Society of Engineers, Chicago, Ill., on February 27 and 28, 1931. This committee, which is made up of five representatives each of the American Society of Civil Engineers, the American Society for Testing Materials, the American Railway Engineering Association, the Portland Cement Association, and the American Concrete Institute, is a reorganization of the committee that made reports on concrete specifications in 1921 and 1924.

A number of developments since the 1924 report make certain changes in the specification desirable. Among the advances which have been made relating to concrete as a material in recent years, the most significant are the developments in cement, use of ready-mixed concrete, and a more widespread understanding of the design of mixtures with increasing attention to field control.

In the field of design, an outstanding development which should be covered in future reports of the committee, is the tendency toward the greater use of rigid frame construction.

All these developments are to be given consideration by the reorganized committee in addition to a general study of the 1924 report with a view to improving its presentation and widening its scope.

The committee proposes in its report to separate portions which are in the nature of specifications from those which are in the nature of recommended practice. It is planned also to add as an appendix the technical data upon which the recommendations of the report are based. The committee is considering the necessity of distinguishing between the requirements for so-called outdoor concrete and concrete in locations such as heated buildings not exposed to the effect of weather. Water-tightness as an element of durability will be recognized as one of the essentials of concrete for outdoor exposure. The necessity for this has been brought about by the recent development of generally higher strengths in Portland cements. Following the practice which has become quite general of designing concrete for a given strength requirement, it is possible with these newer cements that mixtures will result which are too lean for proper durability. Some limitation will, therefore, be placed upon the cement content to avoid this difficulty.

In the field of design of reinforced concrete, the committee proposes to present the recommendations in regard to moment coefficients by putting primary emphasis on the general case of unequal spans, thus reversing the arrangement in the 1924 report in which the emphasis is placed on a series of equal spans. Moment coefficients will be given only for the case of equal spans and these will be presented with separate coefficients for live and dead load.

The next meeting of the committee has been set for June 22 and 23, 1931, in Chicago.

ADDRESS LIST OF MEMBERS AS OF OCTOBER 2, 1930

REPRESENTING THE AMERICAN CONCRETE INSTITUTE

S. C. Hollister, Chairman, Professor of Structural Engineering, Purdue University, Lafayette, Ind.

J. G. Ahlers, Barney-Ahlers Construction Co., 110 West Fortieth Street, New York, N. Y.

F. H. Jackson, United States Bureau of Public Roads, Washington, D. C.

Lieut. Commander B. Moreell, Bureau of Yards and Docks, Puget Sound Navy Yard, Bremerton, Wash.

N. M. Stineman, editor, CONCRETE, 400 West Madison Street, Chicago, Ill.

REPRESENTING THE AMERICAN RAILWAY ENGINEERING ASSOCIATION

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M. Hirschthal, Concrete Engineer, Delaware, Lackawanna & Western Rd., Hoboken, N. J.

J. B. Hunley, Engineer of Bridges and Structures, Cleveland, Cincinnati, Chicago & St. Louis Ry., Cincinnati, Ohio.

A. R. Ketterson, Assistant Engineer of Bridges, Canadian Pacific Ry., Montreal, Que., Canada.

J. F. Leonard, Engineer of Bridges and Buildings, Pennsylvania Railroad, 729 Pennsylvania Station, Pittsburgh, Pa.

REPRESENTING THE AMERICAN SOCIETY OF CIVIL ENGINEERS

W. A. Slater, Chairman, director, Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pa.

M. N. Clair, Vice President, Thompson & Lichtner Co., Statler Building, Boston, Mass.

A. E. Lindau, President, American System of Reinforcing, 7 South Dearborn Street, Chicago, Ill.

F. E. Richart, Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

W. S. Thomson, Chief Engineer, Kalman Steel Co., Wrigley Building, Chicago, Ill.

REPRESENTING THE AMERICAN SOCIETY FOR TESTING MATERIALS

C. M. Chapman, Chairman, Consulting Engineer, 105 West Fortieth Street, New York, N. Y.

P. H. Bates, United States Bureau of Standards, Washington, D. C.

A. T. Goldbeck, Director, Bureau of Engineering, National Crushed Stone Association, 1735 Fourteenth Street NW., Washington, D. C.

E. E. Hughes, Vice President, Franklin Steel Works, Franklin, Pa.

L. S. Moisseiff, Consulting Engineer, 68 William Street, New York, N. Y.

REPRESENTING THE PORTLAND CEMENT ASSOCIATION

F. R. McMillan, Chairman, Director of Research, Portland Cement Association, 33 West Grand Avenue, Chicago, Ill.

D. A. Abrams, Director of Research, International Cement Corporation, 342 Madison Avenue, New York, N. Y.

Ernest Ashton, Vice President, Lehigh Portland Cement Co., Allentown, Pa.

J. H. Chubb, Manager Service Department, Pennsylvania-Dixie Cement Corporation, 521 Fifth avenue, New York, N. Y.

H. G. Farmer, Manager Service Bureau, Universal Atlas Cement Co., 208 South LaSalle Street, Chicago, Ill.

ANALYSIS OF MOTOR VEHICLE ACCIDENTS IN CALIFORNIA

Reported by the Bureau of Research, Statistics, and Traffic Safety, Division of Motor Vehicles, California Department of Public Works

The motoring public of California started the year 1931 with a 16.08 per cent increase in motor-vehicle accidents and a resulting increase of 16.25 per cent in persons injured and a 9.44 per cent increase in deaths. These increases are computed with the January, 1930, report as a base.

New Year's day traffic was an important factor in January accidents. This is indicated by the large volume of accidents occurring on Thursdays. The same was true in January, 1930, when more accidents occurred on Wednesdays, as January 1, 1930, fell on a Wednesday.

Light conditions under which accidents occured in January, 1931, varied slightly from the average, since considerably more accidents were reported as occurring in darkness than in daylight.

The road location of accidents followed the average in January, with the most accidents at city intersections. "Between intersections" was second greatest in the number of accidents by location. It is of interest to note that 23 accidents occurred on bridges and piers, 6 of which were fatal accidents. This is an increase of over 100 per cent over January, 1930.

A total of 2,325 motorists were reported definitely at fault in January accidents. Of these 608 violated right of way, while 502 drivers came to grief because of too much speed. Nineteen of those reported as driving at excessives speed were involved in fatal accidents.

Although the total of deaths due to traffic accidents in January, 1931, showed an increase of 17 over those occurring in January, 1930, the number of pedestrians killed was 7 less. The largest numerical increases in deaths were in noncollision accidents and collisions of two motor vehicles. The number of persons killed on bicycles increased from 1 in January, 1930, to 4 in January of this year. The 1 person killed on the bicycle in 1930 was a male over 50 years of age, while all of those killed in January of this year were male children less than 20 years of age.

The number of collisions with railroad trains dropped from 61 in January, 1930, to 51 in January, 1931. The injured in this type of accident decreased by 7, but the deaths increased by 2.

Fewer accidents were reported as occurring under inclement weather conditions than in January, 1930, although the total number of accidents in January, 1931, increased more than 16 per cent over the previous year. The following table summarizes the accident statistics for the months of January, 1930, and January, 1931.

TABLE 1.—*Comparative monthly summary of motor vehicle accidents in California, January, 1930, and January, 1931*

Item	Number reported during January, 1931	Number reported during January, 1930
Accidents	2,880	2,481
Persons killed	197	180
Persons injured	3,740	3,217
Drivers involved	4,280	3,644
Pedestrians involved	984	900
Vehicles involved	4,323	3,677

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924.
Report of the Chief of the Bureau of Public Roads, 1925.
Report of the Chief of the Bureau of Public Roads, 1927.
Report of the Chief of the Bureau of Public Roads, 1928.
Report of the Chief of the Bureau of Public Roads, 1929.
Report of the Chief of the Bureau of Public Roads, 1930.

DEPARTMENT BULLETINS

No. *136D. Highway Bonds. 20c.
*314D. Methods for the Examination of Bituminous Road Materials. 10c.
*347D. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*532D. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*583D. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.
*660D. Highway Cost Keeping. 10c.
*691D. Typical Specifications for Bituminous Road Materials. 10c.
1216D. Tentative Standard Methods of Sampling and Testing Highway Materials, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.
1279D. Rural Highway Mileage, Income, and Expenditures 1921 and 1922.
1486D. Highway Bridge Location.

DEPARTMENT CIRCULARS

No. 331C. Standard Specifications for Corrugated Metal Pipe Culverts.

TECHNICAL BULLETIN

No. 55T. Highway Bridge Surveys.

MISCELLANEOUS CIRCULARS

No. 62M. Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects.
*93M. Direct Production Costs of Broken Stone. 25c.
109M. Federal Legislation and Regulations Relating to the Improvement of Federal-Aid Roads and National Forest Roads and Trails, Flood Relief, and Miscellaneous Matters.

MISCELLANEOUS PUBLICATIONS

No. 76MP. The Results of Physical Tests of Road-Building Rock.

SEPARATE REPRINTS FROM THE YEARBOOK

No. *914Y. Highways and Highway Transportation. 25c.
937Y. Miscellaneous Agricultural Statistics.
1036Y. Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio. (1927)

Report of a Survey of Transportation on the State Highways of Vermont. (1927)

Report of a Survey of Transportation on the State Highways of New Hampshire. (1927)

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio. (1928)

Report of a Survey of Transportation on the State Highways of Pennsylvania. (1928)

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D- 2. Effect of Controllable Variables upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 19, D- 3. Relation Between Properties of Hardness and Toughness of Road-Building Rock.
Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

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*Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CURRENT STATUS OF FEDERAL-AID ROAD CONSTRUCTION

AS OF

MARCH 31, 1931

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS	STATE
		Estimated total cost	Federal aid allotted	MILEAGE			Estimated total cost	Federal aid allotted	MILEAGE				
				Initial	Stage[1]	Total			Initial	Stage[1]	Total		
		$	$				$	$				$	
Alabama	2,207.1	4,894,519.03	2,373,390.47	197.2	16.3	213.5	2,187,082.10	1,082,215.79	10.2	102.7	112.9	3,724,484.70	Alabama
Arizona	889.8	4,409,048.73	3,132,979.76	166.5	156.6	323.1	286,217.32	147,076.74	5.6	32.8	38.4	1,557,287.14	Arizona
Arkansas	1,811.9	6,998,220.81	3,257,948.10	205.6	19.5	225.1	2,565,788.51	1,197,999.92	51.0	60.2	111.2	922,151.74	Arkansas
California	1,965.1	8,267,253.92	3,523,747.83	207.4	30.8	238.2	2,866,293.89	892,191.78	76.1	10.9	87.0	2,954,988.82	California
Colorado	1,272.9	5,192,335.14	2,739,453.84	171.2	89.0	260.2	1,421,533.59	770,305.12	63.0	21.4	84.4	2,508,186.97	Colorado
Connecticut	258.2	3,293,772.72	1,346,102.89	27.9		27.9	1,149,310.11	327,514.39	11.3		11.3	309,790.28	Connecticut
Delaware	318.9	158,645.85	79,322.92	4.7		4.7	943,646.53	471,068.76	51.5		51.5	154,916.86	Delaware
Florida	540.0	4,455,392.05	2,169,110.72	108.7		108.7	979,577.36	417,791.90	35.8		35.8	2,076,433.95	Florida
Georgia	2,709.7	9,172,634.95	4,458,363.54	309.4	124.9	434.3	1,410,085.99	667,287.66	49.7	10.3	60.0	2,094,371.49	Georgia
Idaho	1,297.3	2,577,766.53	1,536,381.34	170.5	11.3	181.8	1,782,595.27	918,466.56	109.5	21.0	130.5	846,665.90	Idaho
Illinois	2,196.6	21,311,306.12	9,605,378.14	588.3	57.3	645.6	7,119,403.81	3,200,206.17	214.2	4.7	218.9	3,918,451.61	Illinois
Indiana	1,579.0	5,339,933.27	2,756,132.47	126.0		126.0	6,849,442.34	3,015,107.32	205.8		205.8	967,894.59	Indiana
Iowa	3,212.6	1,341,659.85	591,204.69	25.8	17.4	43.2	6,699,677.73	2,764,271.30	141.5	76.1	217.6	4,059.10	Iowa
Kansas	3,084.7	5,503,393.05	2,660,531.09	374.5	20.7	395.2	3,613,063.06	1,667,425.03	168.0	31.4	199.4	1,564,679.47	Kansas
Kentucky	1,555.7	5,218,771.56	2,217,725.08	178.0	81.1	259.1	3,760,288.55	1,141,495.79	82.7	55.7	138.4	648,562.02	Kentucky
Louisiana	1,417.5	7,719,132.62	3,691,621.98	259.3	17.4	276.7	1,860,133.42	758,276.05	21.4	2.6	24.0	153,801.26	Louisiana
Maine	591.3	2,310,424.19	728,331.27	48.5		48.5	2,331,384.44	1,010,338.77	63.1		63.1	1,131,743.95	Maine
Maryland	703.1	283,984.10	78,782.10		3.9	3.9	1,294,458.45	647,229.20	40.4		40.4	353,824.79	Maryland
Massachusetts	711.5	8,366,635.96	2,088,422.83	72.3		72.3	73,542.42	22,980.00	1.5		1.5	2,564,820.29	Massachusetts
Michigan	1,776.6	9,642,210.16	3,954,942.02	231.8	34.2	266.0	1,085,646.44	510,824.65	56.1	1.5	57.6	3,499,413.36	Michigan
Minnesota	4,306.4	2,003,113.07	758,652.69	22.3	92.9	115.2	5,771,663.90	2,358,708.07	54.7	175.7	230.4	673,718.49	Minnesota
Mississippi	1,806.6	1,886,702.79	939,957.96	65.8	42.2	108.0	1,949,364.59	936,100.02	64.8	41.4	106.2	4,141,500.40	Mississippi
Missouri	2,649.1	7,639,914.64	2,891,262.92	167.0	37.5	204.5	3,077,571.56	1,361,369.01	99.9	31.5	131.4	1,548,439.24	Missouri
Montana	1,871.2	8,015,684.60	4,517,527.33	630.7	55.3	686.0	3,548,832.64	1,998,450.70	239.8	95.4	335.2	2,929,482.65	Montana
Nebraska	3,894.5	5,275,495.59	2,533,097.46	245.7	70.6	316.3	2,432,165.66	1,055,330.09	33.7	123.0	156.7	2,724,535.85	Nebraska
Nevada	1,257.4	1,194,347.30	980,506.32	52.4	83.4	135.8	706,398.78	360,707.57	21.8	44.0	65.8	1,436,983.68	Nevada
New Hampshire	392.0	609,439.04	229,098.40	9.7		9.7						568,699.65	New Hampshire
New Jersey	555.2	4,446,706.15	1,346,390.37	60.5		60.5	119,849.30	59,924.65	3.5		3.5	1,431,971.74	New Jersey
New Mexico	2,020.2	4,699,075.31	3,143,300.49	172.4	48.9	221.3	2,056,891.97	1,310,579.34	75.6	69.9	145.5	260,960.16	New Mexico
New York	2,673.0	18,079,910.33	3,689,505.00	235.7		235.7	29,661,824.40	12,344,196.00	517.0	7.0	524.0	412,127.84	New York
North Carolina	1,914.0	5,507,367.12	2,640,929.15	165.8	33.5	199.3	3,351,665.94	1,644,736.53	123.0	19.2	142.2	1,727,318.69	North Carolina
North Dakota	4,550.5	2,087,233.17	1,084,437.89	270.4	133.2	403.6	1,953,879.32	975,638.65	234.2	292.3	526.5	2,072,328.51	North Dakota
Ohio	2,553.2	10,976,392.49	3,346,196.42	147.4	13.2	160.6	3,188,560.83	996,805.81	42.8	15.9	58.7	3,871,247.80	Ohio
Oklahoma	1,979.3	5,019,584.58	2,383,202.70	191.9	66.7	258.6	4,190,287.95	2,294,368.63	163.0	64.6	227.6	194,978.35	Oklahoma
Oregon	1,272.7	6,519,503.58	3,630,485.02	192.3	80.6	272.9	830,591.98	328,200.07	49.2	9.9	59.1	1,211,161.70	Oregon
Pennsylvania	2,658.1	7,304,923.48	2,600,345.48	47.0		47.0	404,741.83	69,187.89	2.9		2.9	5,163,597.04	Pennsylvania
Rhode Island	209.5	1,912,612.98	761,194.76	31.5		31.5	374,296.87	158,994.01	5.3		5.3	398,028.85	Rhode Island
South Carolina	1,798.8	7,276,114.96	3,204,866.40	97.4	192.8	290.2	237,005.12	118,502.55		11.2	11.2	122,309.45	South Carolina
South Dakota	3,785.8	3,411,946.28	1,970,740.20	305.0	66.7	371.7	1,241,982.44	672,141.64	125.6	64.5	190.1	1,655,937.62	South Dakota
Tennessee	1,448.6	3,244,342.67	1,620,847.47	142.0		142.0	1,885,269.67	924,118.77	82.3	13.4	95.7	2,046,515.96	Tennessee
Texas	7,013.4	14,244,502.90	6,197,945.07	671.9	163.7	835.6	7,353,002.48	3,502,890.21	225.0	202.1	427.1	5,271,883.36	Texas
Utah	995.2	1,838,027.51	1,153,291.04	127.7	49.2	176.9	896,755.19	367,461.94	35.2	54.7	89.9	1,108,727.62	Utah
Vermont	303.6	304,277.34	133,620.98	3.2		3.2	960,743.63	385,397.22	23.0		23.0	172,183.53	Vermont
Virginia	1,633.6	4,849,686.85	2,315,051.15	210.7	21.6	232.3	1,069,073.03	395,870.01	34.1	18.0	52.1	1,171,253.49	Virginia
Washington	1,011.1	3,941,957.98	1,783,137.51	127.6	7.7	135.3	1,294,418.39	542,428.75	40.8	12.1	52.9	1,538,767.92	Washington
West Virginia	765.5	4,594,359.59	1,736,464.31	103.6	12.2	115.8	1,464,879.70	544,194.41	36.6	.3	36.9	447,366.80	West Virginia
Wisconsin	2,476.3	3,482,772.05	1,492,374.55	81.8	13.0	94.8	1,284,689.31	572,489.81	50.3	11.7	62.0	2,234,059.16	Wisconsin
Wyoming	1,708.9	3,100,149.80	2,008,346.01	197.5	146.0	343.5	611,757.66	344,850.15	53.8	50.3	104.1	891,809.11	Wyoming
Hawaii	46.3	790,777.25	361,304.04	26.6		26.6	623,763.91	205,849.56	13.5		13.5	1,631,740.97	Hawaii
TOTALS	89,658.5	260,713,962.01	114,443,942.17	8,277.1	2,111.3	10,388.4	132,801,079.38	58,459,564.96	3,909.8	1,859.4	5,769.2	81,016,163.92	TOTALS

[1] The term stage construction refers to additional work done on projects previously improved with Federal aid. In general, such additional work consists of the construction of a surface of higher type than was provided in the initial improvement.

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